Northeast Fisheries Science Center Reference Document 11-01

51st Northeast Regional Stock Assessment Workshop (51st SAW):

Assessment Summary Report

by Northeast Fisheries Science Center

January 2011

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NOAA National Marine Fisheries Service, 166 Water St., Woods Hole, MA 02543.

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

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Northeast Fisheries Science Center Reference Documents

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Editorial Treatment: To distribute this report quickly, it has not undergone the normal technical and copy editing by the Northeast Fisheries Science Center's (NEFSC's) Editorial Office as have most other issues in the NOAA Technical Memorandum NMFS-NE series. Other than the four covers and first two preliminary pages, all writing and editing have been performed by the authors listed within. This report was reviewed by the Stock Assessment Review Committee, a panel of assessment experts from the Center for Independent Experts (CIE), University of Miami.

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A Report of the 51st Northeast Regional Stock Assessment Workshop

51st Northeast Regional Stock Assessment Workshop (51st SAW)

Assessment Summary Report

U.S DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

January 2011

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SAW-51 ASSESSMENT SUMMARY REPORT

Introduction

The 51st SAW Assessment Summary Report contains summary and detailed technical information on three stock assessments reviewed in November-December 2010 at the Stock Assessment Workshop (SAW) by the 51st Stock Assessment Review Committee (SARC-51): Silver Hake (also called whiting; *Merluccius bilinearis*), Longfin Inshore Squid (*Loligo pealeii*), Red Hake (commonly known as ling; *Urophycis chuss*) and Offshore Hake (also known as whiting or black-eye whiting; *Merluccius albidus*). The SARC-51 consisted of 3 external, independent reviewers appointed by the Center for Independent Experts (CIE) and an external SARC chairman from the New England Fishery Management Council Science and Statistics Committee (NEFMC SSC). The SARC evaluated whether each Term of Reference (listed in the Appendix) was completed successfully based on whether the work provided a scientifically credible basis for developing fishery management advice. The reviewers' reports for SAW/SARC-51 are available at website: http://www.nefsc.noaa.gov/nefsc/saw/ under the heading "SARC 51 Panelist Reports".

An important aspect of any assessment is the determination of current stock status. The status of the stock relates to both the rate of removal of fish from the population – the exploitation rate – and the current stock size. The exploitation rate is the proportion of the stock alive at the beginning of the year that is caught during the year. When that proportion exceeds the amount specified in an overfishing definition, overfishing is occurring. Fishery removal rates are usually expressed in terms of the instantaneous fishing mortality rate, F, and the maximum removal rate is denoted as $F_{THRESHOLD.}$

Another important factor for classifying the status of a resource is the current stock level, for example, spawning stock biomass (SSB) or total stock biomass (TSB). Overfishing definitions, therefore, characteristically include specification of a minimum biomass threshold as well as a maximum fishing threshold. If the biomass of a stock falls below the biomass threshold ($B_{THRESHOLD}$) the stock is in an overfished condition. The Sustainable Fisheries Act mandates that a stock rebuilding plan be developed should this situation arise.

As there are two dimensions to stock status – the rate of removal and the biomass level – it is possible that a stock not currently subject to overfishing in terms of exploitation rates is in an overfished condition, that is, has a biomass level less than the threshold level. This may be due to heavy exploitation in the past, or a result of other factors such as unfavorable environmental conditions. In this case, future recruitment to the stock is very important and the probability of improvement may increase greatly by increasing the stock size. Conversely, fishing down a stock that is at a high biomass level should generally increase the long-term sustainable yield. Stocks under federal jurisdiction are managed on the basis of maximum sustainable yield (MSY). The biomass that produces this yield is called B_{MSY} and the fishing mortality rate that produces MSY is called F_{MSY}.

Given this, federally managed stocks under review are classified with respect to current overfishing definitions. A stock is overfished if its current biomass is below $B_{THRESHOLD}$ and overfishing is occurring if current F is greater than $F_{THRESHOLD.}$ The table below depicts status criteria.

		BIOMASS		
		$B < B_{THRESHOLD}$	$B_{THRESHOLD} < B < B_{MSY}$	$B > B_{MSY}$
EXPLOITATION RATE	$F > F_{THRESHOLD}$	Overfished, overfishing is occurring; reduce F, adopt and follow rebuilding plan	Not overfished, overfishing is occurring; reduce F, rebuild stock	$F = F_{TARGET} <= F_{MSY}$
	$F < F_{THRESHOLD}$	Overfished, overfishing is not occurring; adopt and follow rebuilding plan	Not overfished, overfishing is not occurring; rebuild stock	$F = F_{TARGET} <= F_{MSY}$

Fisheries management may take into account the precautionary approach, and overfishing guidelines often include a control rule in the overfishing definition. Generically, the control rules suggest actions at various levels of stock biomass and incorporate an assessment of risk, in that F targets are set so as to avoid exceeding F thresholds.

Outcome of Stock Assessment Review Meeting

Based on the Review Panel reports (available at http://www.nefsc.noaa.gov/nefsc/saw/ under the heading "SARC 51 Panelist Reports"), the SARC review committee concluded that for **silver hake** none of the ASAP models that were examined provided a consistent assessment of the stock in either the northern (N) or southern (S) area. A key issue was whether to allow a domed selectivity assumption, which creates "cryptic" fish. The ASAP model requires improvement before it can serve as a basis for fishery management advice. In the absence of an accepted assessment model, it was not possible to perform multi-year projections. Work on factors affecting catchability across ages and years in the silver hake surveys is required to ensure that apparent mortality can be assigned to fishing, natural factors, changes in distribution or changes in survey catchability. Inclusion of consumption estimates provided perspective on the magnitude of fishery mortality. Based on proposed silver hake biological reference points overfishing is not taking place and the stocks are not overfished in the N or S areas.

The **red hake** assessment moved the understanding of the population and its fisheries forward considerably. Substantial exploratory work was carried out on the age-based data for the survey, fishery and predator consumption using the SS3 and SCALE models, but the diagnostics were not adequate for stock status determination or for provision of management advice. In the absence of an accepted assessment model as a basis for providing management advice, it was not possible to perform multi-year projections. Based on proposed red hake biological reference points overfishing is not taking place and the N and S stocks are not overfished.

This was the first time that an **offshore hake** assessment had been attempted. Although the Hake Working Group did a thorough job, the data are insufficient to complete an assessment. The major shortcoming is that the surveys are believed to cover an unknown and variable proportion of the stock. The Panel concluded that sufficient information is not available to determine stock status with confidence, because fishery data are insufficient and one cannot assume that survey data reflect stock trends. The Panel concluded that it is not possible at this time to provide a reliable definition for overfished and overfishing for this stock.

The majority of SARC panelists consider the ***Loligo*** assessment to be adequate for developing annual management advice as long as the exploitation rate stays low. The SARC accepted a newly proposed B_{MSY} proxy, but expressed concerns. During 2009, the *Loligo* stock was not overfished and overfishing was probably not occurring. No overfishing threshold has been recommended, which leaves overfishing status officially unknown. Better understanding of seasonal cohort recruitment, growth rate, mortality, catch and effort, might allow within-season or within-year management schemes.

Glossary

ADAPT. A commonly used form of computer program used to optimally fit a Virtual Population Assessment (VPA) to abundance data.

ASAP. The Age Structured Assessment Program is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. Discards can be treated explicitly. The separability assumption is relaxed by allowing for fleet-specific computations and by allowing the selectivity at age to change smoothly over time or in blocks of years. The software can also allow the catchability associated with each abundance index to vary smoothly with time. The problem's dimensions (number of ages, years, fleets and abundance indices) are defined at input and limited by hardware only. The input is arranged assuming data is available for most years, but missing years are allowed. The model currently does not allow use of length data nor indices of survival rates. Diagnostics include index fits, residuals in catch and catch-at-age, and effective sample size calculations. Weights are input for different components of the objective function and allow for relatively simple age-structured production model type models up to fully parameterized models.

ASPM. Age-structured production models, also known as statistical catch-at-age (SCAA) models, are a technique of stock assessment that integrate fishery catch and fishery-independent sampling information. The procedures are flexible, allowing for uncertainty in the absolute magnitudes of catches as part of the estimation. Unlike virtual population analysis (VPA) that tracks the cumulative catches of various year classes as they age, ASPM is a forward projection simulation of the exploited population. ASPM is similar to the NOAA Fishery Toolbox applications ASAP (Age Structured Assessment Program) and SS2 (Stock Synthesis 2)

Availability. Refers to the distribution of fish of different ages or sizes relative to that taken in the fishery.

Biological reference points. Specific values for the variables that describe the state of a fishery system which are used to evaluate its status. Reference points are most often specified in terms of fishing mortality rate and/or spawning stock biomass. The reference points may indicate 1) a desired state of the fishery, such as a fishing mortality rate that will achieve a high level of sustainable yield, or 2) a state of the fishery that should be avoided, such as a high fishing mortality rate which risks a stock collapse and long-term loss of potential yield. The former type of reference points are referred to as "target reference points" and the latter are referred to as "limit reference points" or "thresholds". Some common examples of reference points are $F_{0.1}$, F_{MAX}, and F_{MSY}, which are defined later in this glossary.

B_0. Virgin stock biomass, i.e., the long-term average biomass value expected in the absence of fishing mortality.

B_{MSY}. Long-term average biomass that would be achieved if fishing at a constant fishing mortality rate equal to F_{MSY}.

Biomass Dynamics Model. A simple stock assessment model that tracks changes in stock using assumptions about growth and can be tuned to abundance data such as commercial catch rates, research survey trends or biomass estimates.

Catchability. Proportion of the stock removed by one unit of effective fishing effort (typically age-specific due to differences in selectivity and availability by age).

Control Rule. Describes a plan for pre-agreed management actions as a function of variables related to the status of the stock. For example, a control rule can specify how F or yield should vary with biomass. In the National Standard Guidelines (NSG), the "MSY control rule" is used to determine the limit fishing mortality, or Maximum Fishing Mortality Threshold (MFMT). Control rules are also known as "decision rules" or "harvest control laws."

Catch per Unit of Effort (CPUE). Measures the relative success of fishing operations, but also can be used as a proxy for relative abundance based on the assumption that CPUE is linearly related to stock size. The use of CPUE that has not been properly standardized for temporal-spatial changes in catchability should be avoided.

Exploitation pattern. The fishing mortality on each age (or group of adjacent ages) of a stock relative to the highest mortality on any age. The exploitation pattern is expressed as a series of values ranging from 0.0 to 1.0. The pattern is referred to as "flat-topped" when the values for all the oldest ages are about 1.0, and "dome-shaped" when the values for some intermediate ages are about 1.0 and those for the oldest ages are significantly lower. This pattern often varies by type of fishing gear, area, and seasonal distribution of fishing, and the growth and migration of the fish. The pattern can be changed by modifications to fishing gear, for example, increasing mesh or hook size, or by changing the proportion of harvest by gear type.

Mortality rates. Populations of animals decline exponentially. This means that the number of animals that die in an "instant" is at all times proportional to the number present. The decline is defined by survival curves such as: $N_{t+1} = N_t e^{-z}$

where N_t is the number of animals in the population at time t and N_{t+1} is the number present in the next time period; Z is the total instantaneous mortality rate which can be separated into deaths due to fishing (fishing mortality or F) and deaths due to all other causes (natural mortality or M) and e is the base of the natural logarithm (2.71828).To better understand the concept of an instantaneous mortality rate, consider the following example. Suppose the instantaneous total mortality rate is 2 (i.e., Z = 2) and we want to know how many animals out of an initial population of 1 million fish will be alive at the end of one year. If the year is apportioned into 365 days (that is, the 'instant' of time is one day), then 2/365 or 0.548% of the population will die each day. On the first day of the year, 5,480 fish will die (1,000,000 x 0.00548), leaving 994,520 alive. On day 2, another 5,450 fish die (994,520 x 0.00548) leaving 989,070 alive. At the end of the year, 134,593 fish [1,000,000 x $(1 - 0.00548)^{365}$] remain alive. If, we had instead selected a smaller 'instant' of time, say an hour, 0.0228% of the population would have died by the end of the first time interval (an hour), leaving 135,304 fish alive at the end of the year [1,000,000 x $(1 - 0.00228)^{8760}$]. As the instant of time becomes shorter and shorter, the exact answer to the number of animals surviving is given by the survival curve mentioned above, or, in this example:

$N_{t+1} = 1{,}000{,}000e^{-2} = 135{,}335$ fish

Exploitation rate. The proportion of a population alive at the beginning of the year that is caught during the year. That is, if 1 million fish were alive on January 1 and 200,000 were caught during the year, the exploitation rate is 0.20 (200,000 / 1,000,000) or 20%.

F_{MAX}. The rate of fishing mortality that produces the maximum level of yield per recruit. This is the point beyond which growth overfishing begins.

$F_{0.1}$. The fishing mortality rate where the increase in yield per recruit for an increase in a unit of effort is only 10% of the yield per recruit produced by the first unit of effort on the unexploited stock (i.e., the slope of the yield-per-recruit curve for the $F_{0.1}$ rate is only one-tenth the slope of the curve at its origin).

$F_{10\%}$. The fishing mortality rate which reduces the spawning stock biomass per recruit (SSB/R) to 10% of the amount present in the absence of fishing. More generally, Fx%, is the fishing mortality rate that reduces the SSB/R to x% of the level that would exist in the absence of fishing.

F_{MSY}. The fishing mortality rate that produces the maximum sustainable yield.

Fishery Management Plan (FMP). Plan containing conservation and management measures for fishery resources, and other provisions required by the MSFCMA, developed by Fishery Management Councils or the Secretary of Commerce.

Generation Time. In the context of the National Standard Guidelines, generation time is a measure of the time required for a female to produce a reproductively-active female offspring for use in setting maximum allowable rebuilding time periods.

Growth overfishing. The situation existing when the rate of fishing mortality is above F_{MAX} and when fish are harvested before they reach their growth potential.

Limit Reference Points. Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low. In the National Standard Guidelines, limits are referred to as thresholds. In much of the international literature (e.g., FAO documents), "thresholds" are used as buffer points that signal when a limit is being approached.

Landings per Unit of Effort (LPUE). Analogous to CPUE and measures the relative success of fishing operations, but is also sometimes used a proxy for relative abundance based on the assumption that CPUE is linearly related to stock size.

MSFCMA. (Magnuson-Stevens Fishery Conservation and Management Act). U.S. Public Law 94-265, as amended through October 11, 1996. Available as NOAA Technical Memorandum NMFS-F/SPO-23, 1996.

Maximum Fishing Mortality Threshold (MFMT, $F_{THRESHOLD}$). One of the Status Determination Criteria (SDC) for determining if overfishing is occurring. It will usually be equivalent to the F corresponding to the MSY Control Rule. If current fishing mortality rates are above $F_{THRESHOLD}$, overfishing is occurring.

Minimum Stock Size Threshold (MSST, $B_{THRESHOLD}$). Another of the Status Determination Criteria. The greater of (a) ½B_{MSY}, or (b) the minimum stock size at which rebuilding to B_{MSY} will occur within 10 years of fishing at the MFMT. MSST should be measured in terms of spawning biomass or other appropriate measures of productive capacity. If current stock size is below $B_{THRESHOLD}$, the stock is overfished.

Maximum Spawning Potential (MSP). This type of reference point is used in some fishery management plans to define overfishing. The MSP is the spawning stock biomass per recruit (SSB/ R) when fishing mortality is zero. The degree to which fishing reduces the SSB/R is expressed as a percentage of the MSP (i.e., %MSP). A stock is considered overfished when the fishery reduces the %MSP below the level specified in the overfishing definition. The values of %MSP used to define overfishing can be derived from stock-recruitment data or chosen by analogy using available information on the level required to sustain the stock.

Maximum Sustainable Yield (MSY). The largest average catch that can be taken from a stock under existing environmental conditions.

Overfishing. According to the National Standard Guidelines, "overfishing occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis." Overfishing is occurring if the MFMT is exceeded for 1 year or more.

Optimum Yield (OY). The amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems. MSY constitutes a "ceiling" for OY. OY may be lower than MSY, depending on relevant economic, social, or ecological factors. In the case of an overfished fishery, OY should provide for rebuilding to B_{MSY}.

Partial Recruitment. Patterns of relative vulnerability of fish of different sizes or ages due to the combined effects of selectivity and availability.

Rebuilding Plan. A plan that must be designed to recover stocks to the B_{MSY} level within 10 years when they are overfished (i.e. when B < MSST). Normally, the 10 years would refer to an expected time to rebuilding in a probabilistic sense.

Recruitment. This is the number of young fish that survive (from birth) to a specific age or grow to a specific size. The specific age or size at which recruitment is measured may correspond to when the young fish become vulnerable to capture in a fishery or when the number of fish in a cohort can be reliably estimated by a stock assessment.

Recruitment overfishing. The situation existing when the fishing mortality rate is so high as to cause a reduction in spawning stock which causes recruitment to become impaired.

Recruitment per spawning stock biomass (R/SSB). The number of fishery recruits (usually age 1 or 2) produced from a given weight of spawners, usually expressed as numbers of recruits per kilogram of mature fish in the stock. This ratio can be computed for each year class and is often used as an index of pre-recruit survival, since a high R/SSB ratio in one year indicates above-average numbers resulting from a given spawning biomass for a particular year class, and vice versa.

Reference Points. Values of parameters (e.g. B_{MSY}, F_{MSY}, $F_{0.1}$) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability (e.g., MSST) or targets for management (e.g., OY).

Risk. The probability of an event times the cost associated with the event (loss function). Sometimes "risk" is simply used to denote the probability of an undesirable result (e.g. the risk of biomass falling below MSST).

Status Determination Criteria (SDC). Objective and measurable criteria used to determine if a stock is being overfished or is in an overfished state according to the National Standard Guidelines.

Selectivity. Measures the relative vulnerability of different age (size) classes to the fishing gears(s).

Spawning Stock Biomass (SSB). The total weight of all sexually mature fish in a stock.

Spawning stock biomass per recruit (SSB/R or SBR). The expected lifetime contribution to the spawning stock biomass for each recruit. SSB/R is calculated assuming that F is constant over the life span of a year class. The calculated value is also dependent on the exploitation pattern and rates of growth and natural mortality, all of which are also assumed to be constant.

Stock Synthesis (SS). This application provides a statistical framework for calibration of a population dynamics model using a diversity of fishery and survey data. SS is designed to accommodate both age and size structure and with multiple stock sub-areas. Selectivity can be cast as age specific only, size-specific in the observations only, or size-specific with the ability to capture the major effect of size-specific survivorship. The overall model contains subcomponents which simulate the population dynamics of the stock and fisheries, derive the expected values for the various observed data, and quantify the magnitude of difference between observed and expected data. Parameters are searched for which will maximize the goodness-of-fit. A management layer is also included in the model allowing uncertainty in estimated parameters to be propagated to the management quantities, thus facilitating a description of the risk of various possible management scenarios. The structure of SS allows for building of simple to complex models depending upon the data available.

Survival Ratios. Ratios of recruits to spawners (or spawning biomass) in a stock-recruitment analysis. The same as the recruitment per spawning stock biomass (R/SSB), see above.

TAC. Total allowable catch is the total regulated catch from a stock in a given time period, usually a year.

Target Reference Points. Benchmarks used to guide management objectives for achieving a desirable outcome (e.g., OY). Target reference points should not be exceeded on average.

Uncertainty. Uncertainty results from a lack of perfect knowledge of many factors that affect stock assessments, estimation of reference points, and management. Rosenberg and Restrepo (1994) identify 5 types: measurement error (in observed quantities), process error (or natural population variability), model error (mis-specification of assumed values or model structure), estimation error (in population parameters or reference points, due to any of the preceding types of errors), and implementation error (or the inability to achieve targets exactly for whatever reason)

Virtual population analysis (VPA) (or cohort analysis). A retrospective analysis of the catches from a given year class which provides estimates of fishing mortality and stock size at each age over its life in the fishery. This technique is used extensively in fishery assessments.

Year class (or cohort). Fish born in a given year. For example, the 1987 year class of cod includes all cod born in 1987. This year class would be age 1 in 1988, age 2 in 1989, and so on.

Yield per recruit (Y/R or YPR). The average expected yield in weight from a single recruit. Y/R is calculated assuming that F is constant over the life span of a year class. The calculated value is also dependent on the exploitation pattern, rate of growth, and natural mortality rate, all of which are assumed to be constant.

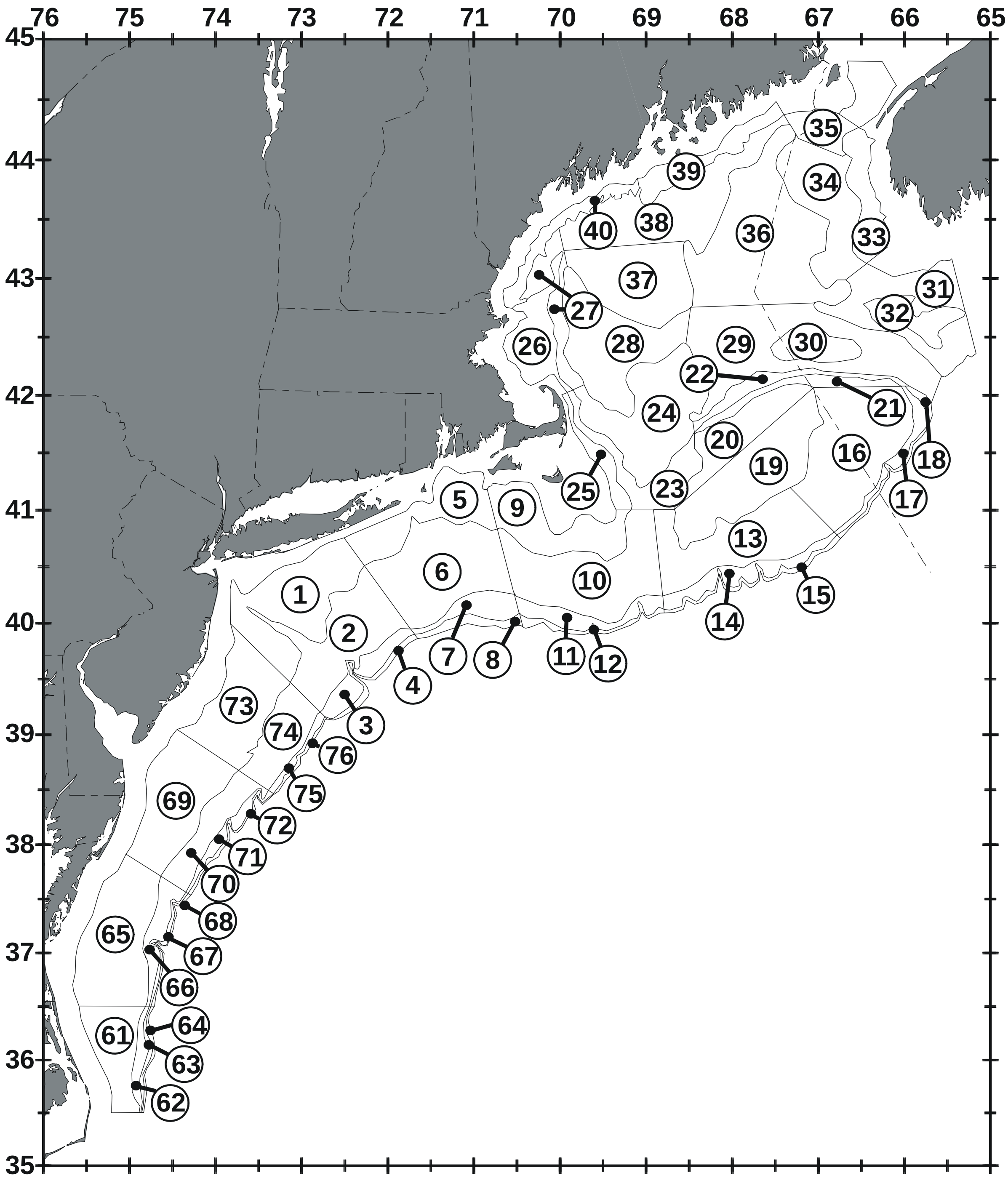

Figure 1. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

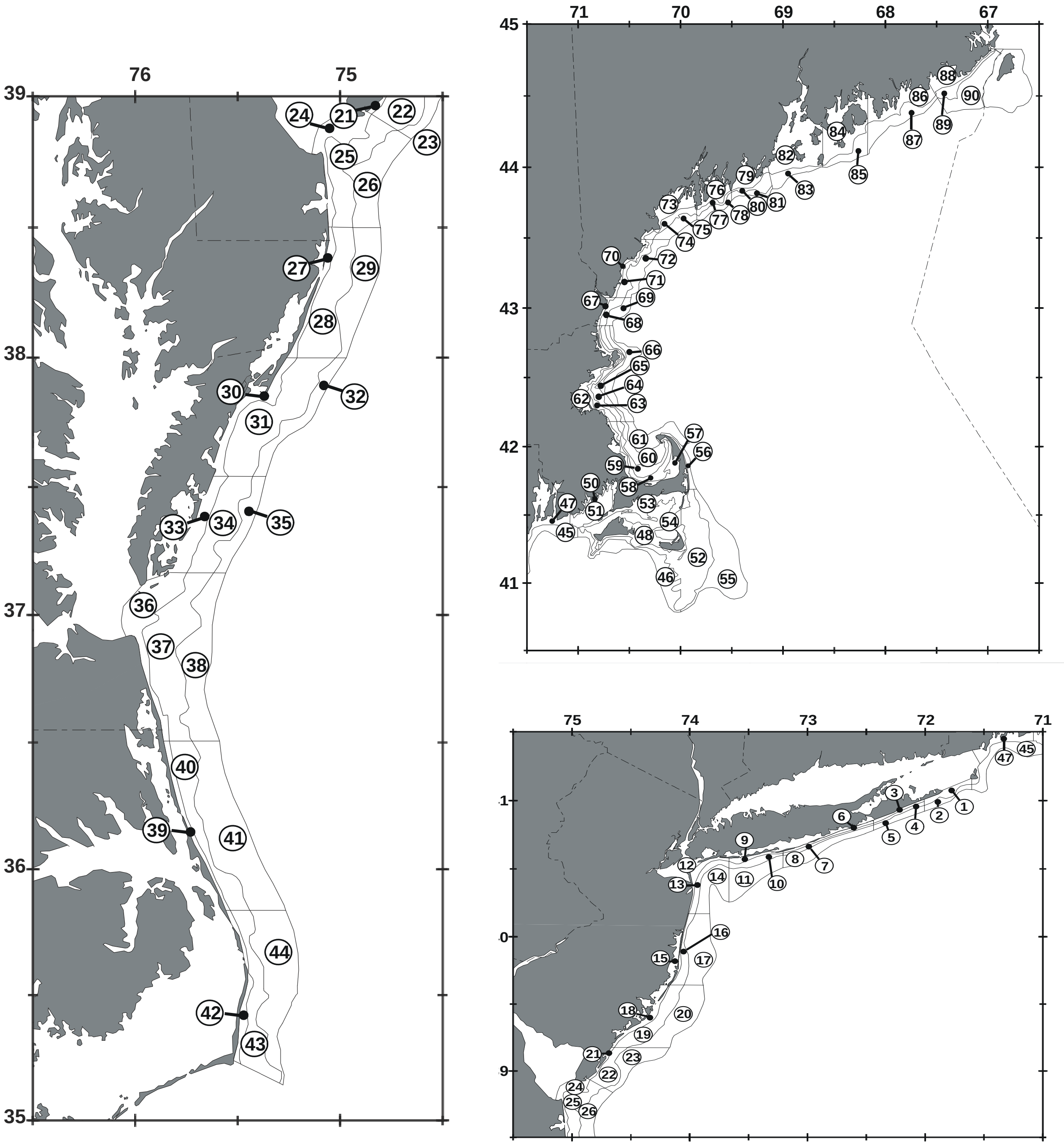

Figure 2. Inshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

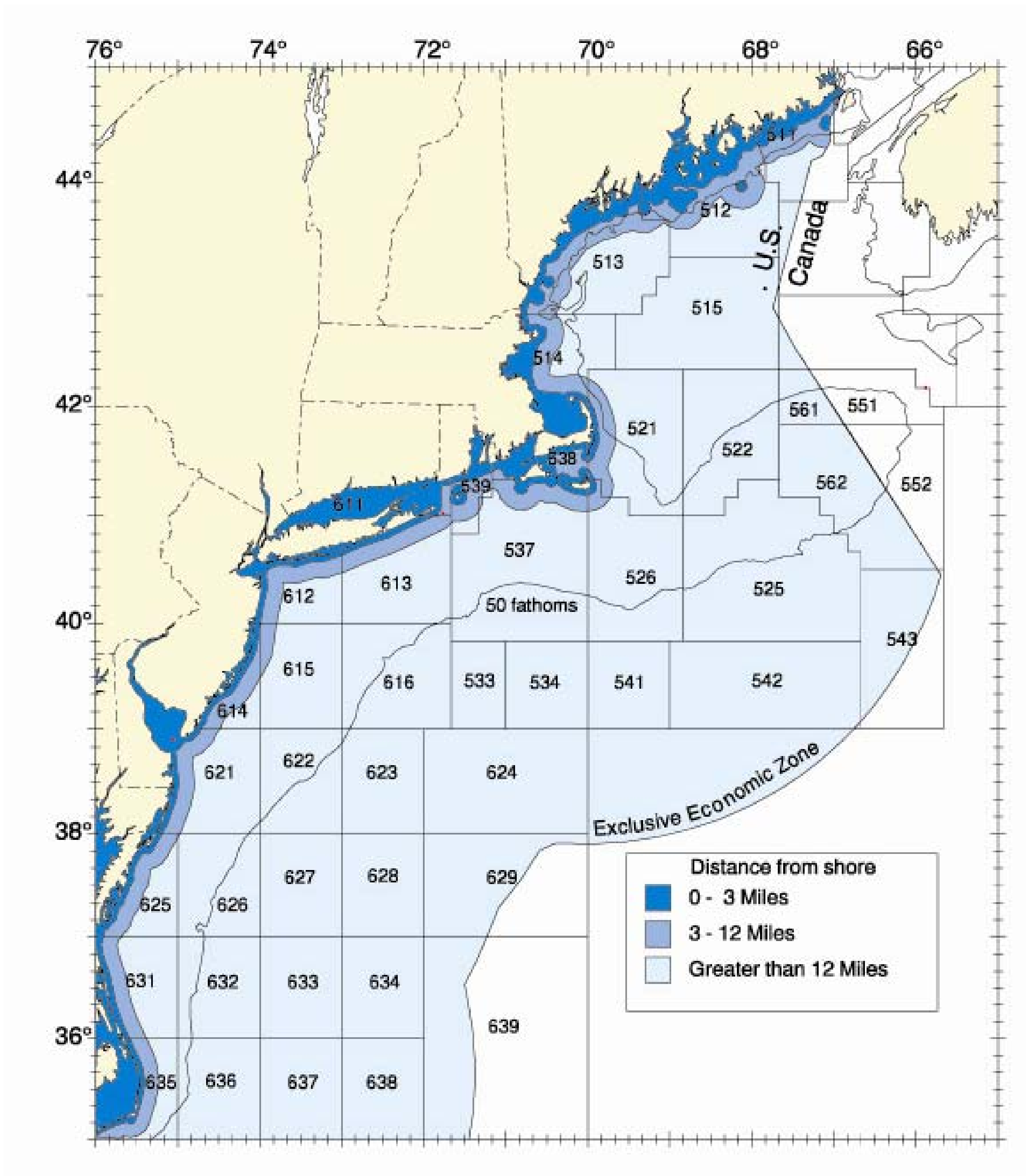

Figure 3. Statistical areas used for reporting commercial catches.

A. SILVER HAKE ASSESSMENT SUMMARY FOR 2010

State of Stock

Stock status based on the current Biological Reference Points is described first, followed by description of results based on newly proposed BRPs.

Based on the current survey index method and current BRPs, silver hake is not overfished and overfishing is not occurring in the northern or southern management areas (Figure A1). For the northern area, the year delta mean biomass index (Figure A2) from the NEFSC fall bottom trawl survey during 2007-2009 (6.79 kg/tow) was above the biomass threshold (3.31 kg/tow) and slightly above the biomass target (6.63 kg/tow). The three year average exploitation index (landings divided by survey biomass index for 2007-2009 (0.13) in the north was less than the exploitation threshold and target (2.57, Figure A3). In the southern area, the three year survey biomass index (1.39 kg/tow) was greater than the biomass threshold (0.89 kg/tow) but below the biomass target (1.78 kg/tow, Figure A4). The three year exploitation index for 2007-2009 (4.33) in the south was below the overfishing threshold (34.39) and target (20.63) (Figure A5).

This year, an age-based analytical assessment (ASAP) for silver hake was attempted based on a "combined" (North + South) assessment area, and including estimates of fishery landings, discards, and predator consumption, by age class. The results were sensitive to model configurations indicating low biomass and high fishing mortality when selectivity was assumed to be flat topped, and high biomass and low fishing mortality when a dome was allowed to be fitted. The ASAP model was not accepted because the reasons for these inconsistencies are not understood. As a result, the existing survey index method was carried forward for this assessment, by management area, but with the fall survey arithmetic means and catch (landings + discards) rather than the previously used delta means and landings.

Based on newly proposed reference points which use arithmetic means, the northern stock of silver hake is not overfished and overfishing is not occurring. The three year average arithmetic mean biomass (Figure A6), based on the NEFSC fall bottom trawl survey data for 2007-2009 (6.20kg/tow), was above the proposed management threshold (3.21kg/tow) and below the target (6.42kg/tow). The three year average exploitation index (total catch divided by biomass index) (Figure A7) for 2007 – 2009 (0.20 kt/kg) was below the overfishing threshold (2.78 kt/kg) and target (1.67 kt/kg).

Similarly under the newly proposed reference points, the southern stock of silver hake is not overfished and overfishing is not occurring. The three year average arithmetic mean biomass (Figure A8), also based on the NESFC fall bottom trawl survey data for 2007-2009 (1.11 kg/tow), was above the biomass threshold (0.83 kg/tow) and below the target (1.65 kg/tow). The three year average exploitation index, for 2007-2009 (5.87 kt/kg) (Figure A9) was below the overfishing threshold (52.30 kt/kg) and target (31.38 kt/kg).

Projections
There is no accepted analytical assessment of the stock and it is not possible to carry out multiyear projections.

Catches
Nominal (reported) annual landings from the northern area were high in the 1950s and 1960s averaging 52,200 mt, followed by a period of lower landings (30,850 mt) through 1975 (Figure A10). After the industrial and distant water fleet fisheries ended in the late 1970s, landings averaged only 8,000 mt. From 2005-2009, annual landings declined to about 1000 mt.

Nominal annual landings from the southern area averaged 14,700 mt in the 1950s, followed by a period of extremely high landings over 300,000 mt in 1965 (Figure A12). Landings then averaged 61,000 mt during the 1970s. After the industrial and distant water fleet fisheries ended in the late 1970s, landings averaged only 12,000 mt through 1999. From 2001-2009, annual landings declined to about 7000 mt.

Prior to 1991 landings of silver hake and offshore hake were not reported by species. Since 1991 reporting by species has occurred but to varying extents. This introduces a source of uncertainty in landings data particularly for the southern region where offshore hake are more abundant (Garcia-Vazquez et al., 2009). Therefore, two models (length-based and depth-based estimators) were developed to estimate the proportion of silver hake landed from the total hake landings (offshore and silver hake combined). Both methods rely on length-based or depth-dependent species compositions in the NEFSC trawl surveys. The two models provided similar estimates of proportion of silver hake, averaging 94-96% of nominal combined-species landings (Figure A11). The assessment is therefore insensitive to choice of model. The length-based landings estimates were used in the assessment because they were based on fewer assumptions.

Estimated annual discards of silver hake in the north ranged from 38 mt (2006) to 2,900 mt (1982) (Figure A11). Estimated annual discards of silver hake in the south ranged from 131 mt (2007) to 6,600 mt (1989) (Figure A13). Data on discards at age are available only from 1989, with age-aggregated estimates back to 1981.

Catch and Status Table (weights in mt): Silver Hake

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Max[1]	Min[1]	Mean[1]
Nominal Commercial Landings													
Northern Stock													
US	2592	3391	2593	1808	1049	827	903	1014	620	1038	62750	620	14952
DWF[2]											57240	2	18904
Total	2592	3391	2593	1808	1049	827	903	1014	620	1038	94462	620	20452
Southern Stock													
US	9769	9517	5344	6835	7436	6670	4629	5345	5638	6720	26518	4629	11132
DWF[2]											283366	2	56349
Total	9769	9517	5344	6835	7436	6670	4629	5345	5638	6720	307131	4629	37769
Combined Stock													
US	12361	12908	7937	8643	8485	7497	5532	6359	6258	7755	79903	5532	26084
DWF[2]											299159	2	67982
Total	12361	12908	7937	8643	8485	7497	5532	6359	6258	7758	352410	5532	58221
Length-Based Model Landings – Southern Stock													
US	9472	8884	4888	6281	6965	6395	4584	5067	5582	6595	25394	4584	10670
DWF[2]											271359	2	54064
Total	9472	8884	4888	6281	6965	6395	4584	5067	5582	6595	294117	4584	36228
Length-Based Model Landings – Combined Stock													
US	12064	12275	7481	8089	8014	7222	5487	6081	6202	7633	79176	5487	25623
DWF[2]											287152	2	65697
Total	12064	12275	7481	8089	8014	7222	5487	6081	6202	7633	339396	5487	56679
Nominal Discards													
Northern	362	477	514	203	115	62	39	750	167	221	2905	39	1159
Southern	333	192	280	676	1244	1574	160	132	1045	828	6642	132	2742
Combined	694	669	794	879	1359	1637	199	882	1213	1049	8984	199	3901
Length-Based Model Discards													
Southern	329	188	410	604	1203	1576	161	146	1033	839	6573	146	2691
Combined	690	665	924	806	1318	1638	200	895	1201	1060	8915	200	3850
Catch Used in Assessment[3]													
Northern	2954	3868	3107	2011	1164	889	942	1764	787	1259	94462	787	21063
Southern	9800	9072	5298	6884	8168	7971	4746	5212	6616	7434	294117	4746	37647
Combined	12754	12940	8405	8895	9332	8860	5687	6976	7403	8693	339396	5687	58709
Arithmetic Biomass (Fall Survey kg/tow)													
North	13.507	8.328	7.988	8.293	3.278	1.716	3.693	6.443	5.274	6.892	23.100	1.716	7.519
South	0.723	2.040	1.176	1.423	1.239	0.941	1.416	0.874	1.363	1.095	5.275	0.447	1.740
Arithmetic 3-year Average Biomass (Fall Survey kg/tow)													
North	14.521	10.994	9.941	8.203	6.519	4.429	2.896	3.951	5.137	6.203	14.521	2.317	7.337
South	0.705	1.195	1.313	1.546	1.279	1.201	1.198	1.077	1.218	1.111	4.667	0.617	1.692
Arithmetic Relative Exploitation (catch/Fall Survey Biomass)													
North	0.219	0.464	0.389	0.242	0.355	0.518	0.255	0.274	0.149	0.183	21.748	0.145	3.357
South	13.549	4.447	4.506	4.837	6.592	8.472	3.353	5.962	4.853	6.787	120.536	3.353	21.969
Arithmetic 3-year Average Relative Exploitation (catch/Fall Survey Biomass)													
North	0.246	0.352	0.357	0.365	0.329	0.372	0.376	0.349	0.226	0.202	14.769	0.202	3.294
South	17.829	11.674	7.501	4.597	5.312	6.634	6.139	5.929	4.722	5.867	74.009	4.597	22.257
Survey Recruitment Abundance[4] (000's)													
North	240420	69302	149828	208367	47123	12764	134985	168273	113613	187421	452389	10959	107972
South	196880	180877	74067	324662	90583	34474	85613	45174	49152	214301	363427	11023	138582

1 Landings data based on 1955-2009 (mt). Commercial fishery discard means from 1981-2009.
2 DWF(Distant Water Fleet) landings are for NAFO Areas 5 and 6.
3 Catch Used in Assessment is the Length-Based Model Estimated Catch.
4 Survey recruitment abundance based on swept area estimates in thousands of fish from 1973-2009.

Stock Distribution and Identification

Silver hake range from Newfoundland to South Carolina and are most abundant from Nova Scotia to New Jersey. Silver hake are found over a wide range of depths, from shallow waters to greater than 400 m (219 fathoms). Larger and older silver hake tend to be found further to the north and in deeper water. There are seasonal patterns with movement inshore during the spring and summer.

Management is based on two stocks (North and South) due to differences in morphology of silver hake in the two areas (Figure A1), population trends, and fishery patterns. The northern stock is distributed in the Gulf of Maine-northern Georges Bank region. The southern stock extends from southern Georges Bank to Cape Hatteras.

There was no strong biological evidence to support either a separate or combined silver hake assessment. The two management units were retained in this assessment.

Data and Assessment

Data available included fishery landings and discards by fleet, length compositions of landings and discards, age-based surveys indices from the NEFSC fall and spring surveys, and estimates of minimum consumption at age for a subset of fish predators sampled for stomach contents on the NEFSC surveys. In contrast to the index method, the ASAP model which was attempted used age structure, additional surveys, more comprehensive information on selectivity and accommodates uncertainty in the input data. These additional data might allow an assessment that can potentially accommodate changes in the silver hake fishery (gear, selectivity, targeting, and management), and the change to a new survey vessel (for which length-based calibration factors have been obtained). The ASAP model attempted to incorporate a measure of predatory consumption which informs the scaling of biomass and the magnitude of mortality estimates.

Catch curves from the NEFSC fall and spring trawl surveys, and from the commercial fishery landings, exhibit a very steep age profile that has become progressively steeper over time, suggesting high and increasing total mortality.

The index method that is being used was based on an update of the previous index method in the 2003 SAFE report. Relative abundance indices and associated reference points were previously based on the delta method estimator. For this new assessment, the “delta” estimators were replaced with arithmetic estimates (i.e. no log transform was applied). The delta transformation inflated the variance of the survey and it also was sensitive to treatment of tows with no catch. As a result, the arithmetic mean is recommended for deriving fall survey estimates. The same years (1973-1982) as used previously were used to define the biomass reference points for the fall survey index. Landings for the period (1973-1982) were used previously to characterize the relative exploitation reference points. However, discards since 1989 can be reliably estimated, so the relative exploitation index is now defined using catch over the relative biomass. Historical discarding, particularly in the Distant Water Fleet, has likely been very small. Therefore, comparison of relative exploitation index based on catch/biomass with reference points based on landings over biomass is justified.

The ASAP model, which was not accepted here, included catch by a directed fleet beginning in year 1973 when age information was available. Discards were included as a separate "fleet" in the model starting in 1981. Consumption was modeled as an additional fleet to represent removals from predation. The estimated mortality from the "fleet" of predators was then considered to be an additional source of natural mortality (termed "M2"). Total annual natural mortality at age from the Consumption models was calculated as M1+M2 where M1 is 0.15, and M2 varies by age and year. A wide range of sensitivity runs were explored varying the selectivity assumptions for the survey and directed fleet, numbers of blocks of years for fitting selectivity, varying the M1 value, and the use of a larger M1 whilst excluding the consumption fleet from the model (a value of M1 = 0.4 provided a similar cumulative survival to age 14 as given by the runs with 0.15+M2). All models included the NEFSC spring and fall bottom trawl surveys. Minimum swept area abundances, annual estimated CV, as well as the age composition for each survey were used in the model.

The ASAP results were sensitive to model configurations indicating low biomass and high fishing mortality when selectivity was assumed to be flat topped, and high biomass and low fishing mortality when a dome was allowed to be fitted. The model was not accepted because the causes of the instability could not be determined. As a result, the existing survey index method was carried forward for this assessment, using the fall survey arithmetic means and total catch rather than the delta means and landings for the northern and southern management areas.

The NEFSC bottom trawl survey switched from the FRV *Albatross IV* to the FSV *Bigelow* in spring 2009. Survey data given here are in "*Albatross IV"* units.

Biological Reference Points

The current overfishing definition for silver hake is as follows:

> *Silver hake is overfished when the three-year moving average of the fall survey weight per tow is less than 3.31 kg/tow and 0.89 kg/tow for the northern and southern stocks respectively, one half of the B_{MSY} proxy (the average observed from 1973 – 1982). If an analytical assessment (e.g. VPA) for silver hake is available, the three-year moving average will be replaced with the terminal year biomass estimate and compared with the mean biomass estimated for 1973 – 1982.*
>
> *Overfishing occurs when fishing mortality, derived from the latest three years of survey data, exceeds F0.1 (0.41 and 0.39 for the northern and southern stocks of silver hake respectively). If an analytical assessment is available, then the terminal year fishing mortality rate will be compared to F0.1.*

Due to difficulties in estimating fishing mortality for silver hake in previous assessments, the New England Fishery Management Council's Whiting Monitoring Committee (WMC) developed a relative exploitation index (landings /survey using delta means) based reference in the interim to assess progress relative to Amendment 12 (SAFE 2002). The exploitation index approach was based on the original reference points to the extent possible (i.e. proxy for F_{MSY}). For the north, the WMC recommended an overfishing threshold and target of 2.57 (delta mean). For the southern area, a target set at 60% of F_{MSY} (20.63) and a threshold of 34.39 was recommended by the WMC.

In the absence of an agreed ASAP model run, the new proposed BRPs for both the northern and southern silver hake stocks are as follows:

> *Silver hake is overfished when the three-year moving average of the fall survey weight per tow (i.e. the biomass threshold) is less than one half the B_{MSY} proxy, where the B_{MSY} proxy is defined as the average observed from 1973-1982. The most recent estimates of the biomass thresholds are 3.21 kg/tow for the northern stock and 0.83 kg/tow for the southern stock.*
> *Overfishing occurs when the ratio between the catch and the arithmetic fall survey biomass index from the most recent three years exceeds the overfishing threshold. The most recent estimates of the overfishing threshold, are 2.78 kt/kg for the northern stock and 52.30 kt/kg for the southern stock of silver hake.*

Overfishing threshold estimates are based on annual exploitation ratios (catch divided by arithmetic fall survey biomass) averaged from 1973-1982. Catch per tow is in "Albatross" units (see Data and Assessment section).

There are indications from the ASAP assessment as well in the trends in age 3 and older silver hake in the NEFSC fall survey that total mortality is increasing (Figure A14). This suggests that the reference points described above may not be appropriate.

Fishing Mortality
The index-based proxy for fishing mortality (three-year average catches divided by fall survey biomass index) has declined substantially since the 1970s in both the northern and southern areas (Fig. A7 and A9) and is currently well below the management threshold/target.

Recruitment
The autumn surveys suggest possibly increasing recruitment in the recent years (Figure A15).

Recruitment trends from the ASAP model at age-1 were relatively insensitive to the model configuration choices, but the magnitude was sensitive to model configuration depending on whether consumption was included or not.

Stock Biomass or SSB
The fall survey biomass indices for the northern stock increased by more than a factor of two between 1970 and 1980, then declined sharply to values close to those recorded in the early 1970s (Fig. A2). In contrast, the spring survey biomass indices have been variable without any clear trend. The fall survey biomass indices for the southern stock declined sharply after the mid 1980s and increased again after 2000, whilst the spring survey showed a much larger decline of around 80% between the 1970s and the 2000s.

Ecosystem Considerations
Total consumptive minimum removals by all consistent silver hake predators, using swept area abundance and assessment estimates of the predators, were consistently around 15 thousand mt per year during the late 1970s and increased to average around 80 thousand mt through the 2000s. These estimates of silver hake consumed by the consistent fish predators in this study

were compared to total catch. Estimates of consumption were lower than the catch at the beginning of the time series, but consumption estimates from 1979 onwards are the dominant source of removals with estimates from 2001-2009 averaging more than ten to twenty times the catch (Figures A16 and A17). Although predation focuses on ages 0-2 the modeled predation focused on age 1 and 2 while the fishery is mostly on 2+.

Special Comments

Stock structure of silver hake continues to be an important consideration for stock assessment. While two management areas are assumed to exist (Almeida, 1987), it is likely that the northern and southern stocks mix on Georges Bank. The extent of mixing remains uncertain. Survey trends indicate that biomass in the northern area is higher than in the southern stock area. The incoherence of the survey trends, especially in the spring relative to the removals in the southern area is likely attributed to movement of silver hake across the traditional stock boundaries, possibly resulting in disproportionate representation of silver hake density in the southern area. The empirical evidence about silver hake stock structure is equivocal. Data exist on morphometrics, tagging, egg distributions, larval distributions, and growth and maturity.

Silver hake are cannibalistic. Based on the NEFSC Food Habits Database, approximately 2% of the silver hake had consumed silver hake. By comparison, goosefish (*Lophius americanus*) only had 0.1% incidence of cannibalism. On average, silver hake comprised 12% of the silver hake diet composition (by weight), a significant, consistent and important prey item. This poses potential circularity in estimating silver hake abundance and silver hake cannibalism, which in turn can inform assessment models to estimate silver hake abundance. To accommodate this, we used swept area abundance estimates for silver hake as a predator of silver hake to help scale the total silver hake consumed by silver hake. The impact of cannibalism on stock-recruit relationships is being investigated.

The accepted catch and survey index-based BRPs do not incorporate age structure and do not include measures of uncertainty. No age-based analytical model formulations (ASAP) were accepted; nonetheless, the model results were informative. The most likely ASAP model (Run 6) did provide indications of trend that were in agreement with the declining age 3+ spawning numbers indicated in the fall NEFSC survey data.

Recent catches have been considerably less than historical ones. However, abundances of age 3+ silver hake in fall NEFSC surveys have been declining since the early 1990s under such catches, possibly for reasons other than only fishing. This suggests that the reference points may not be appropriate.

Research to address fishery selectivity and stock composition (mixing of northern and southern components) and the extent of stock distribution is needed to reconcile issues regarding selectivity in the current ASAP model formulation.

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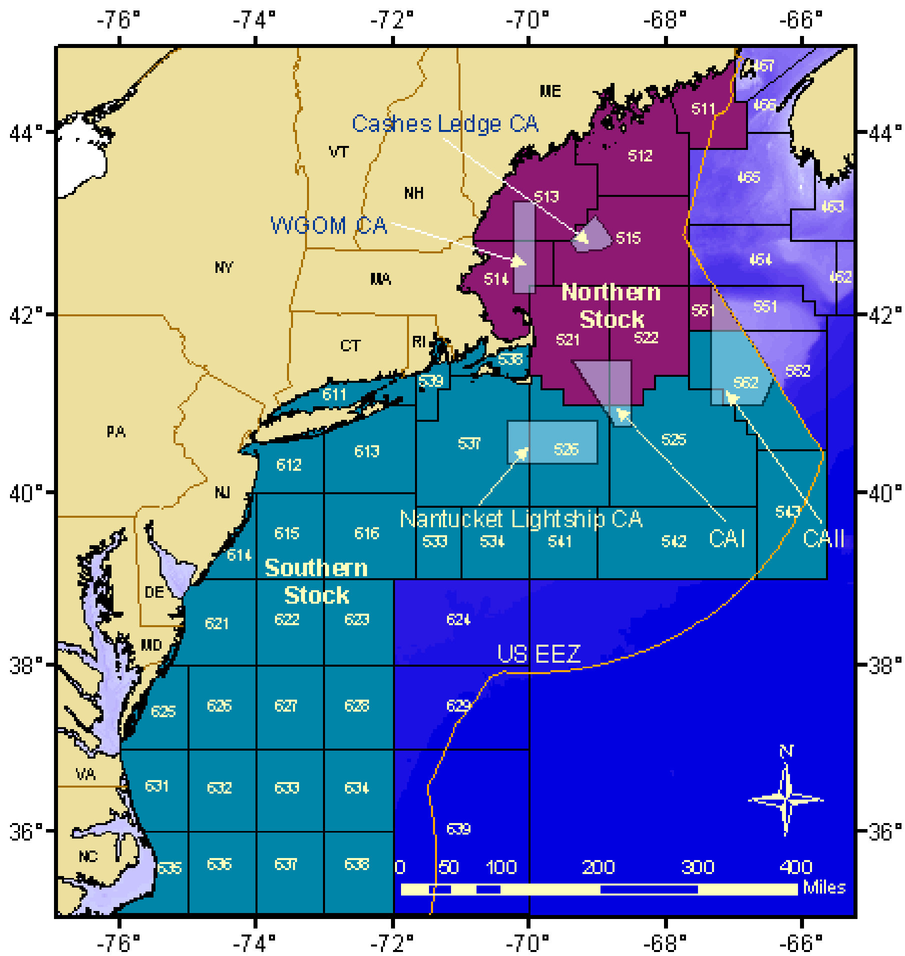
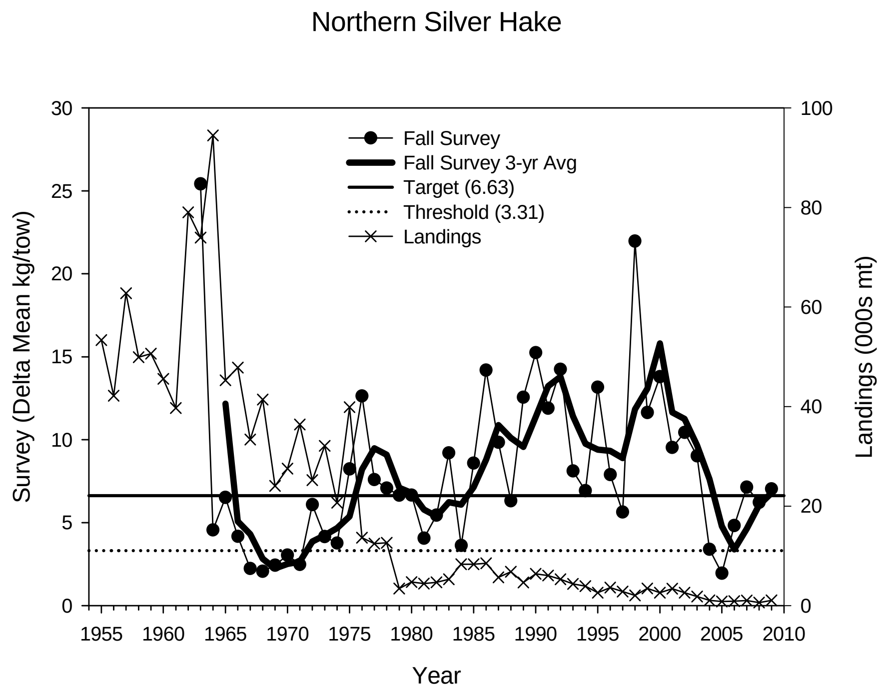
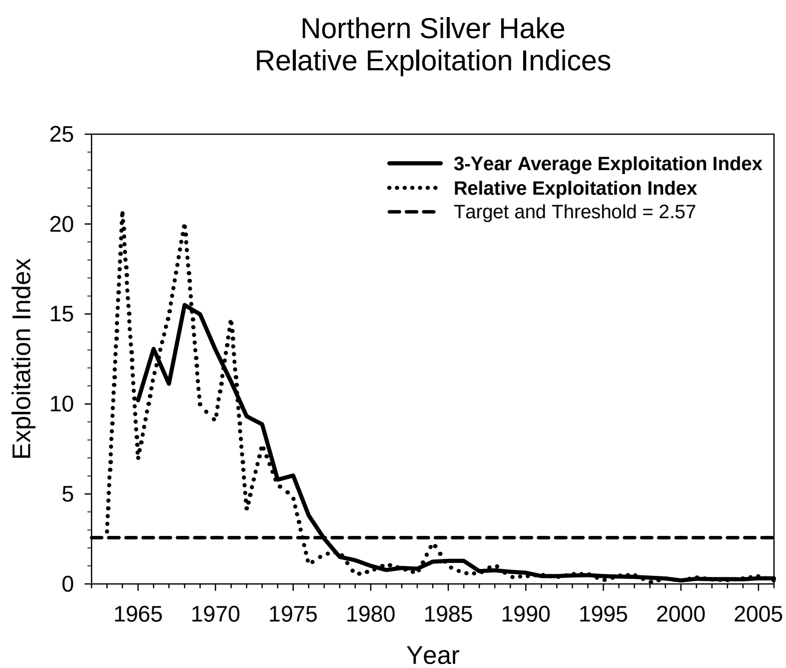


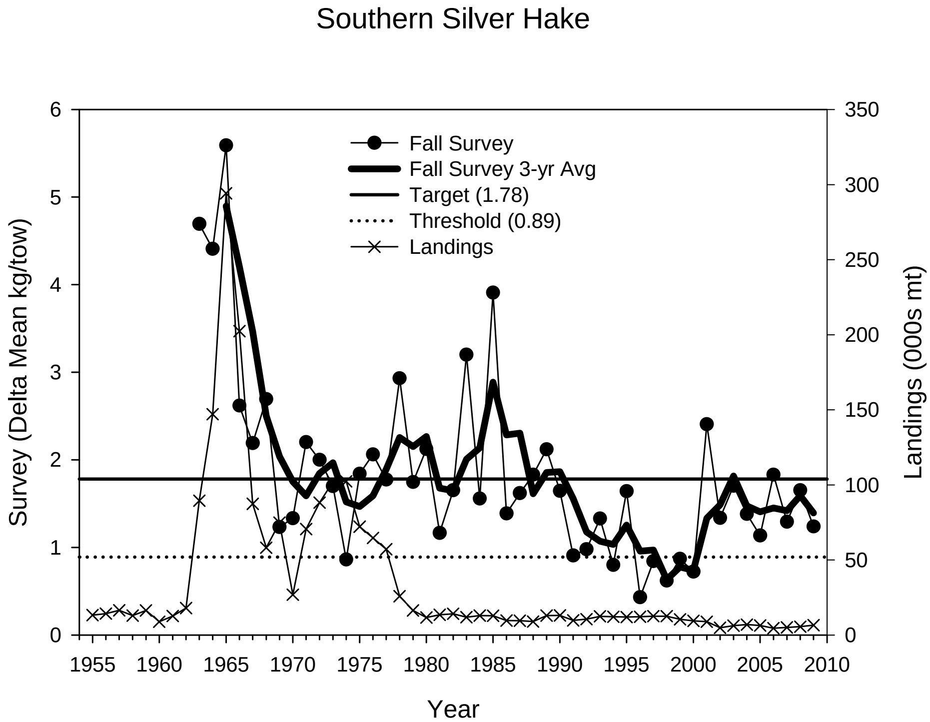
A1. Statistical areas used to define the northern and southern silver hake stocks.



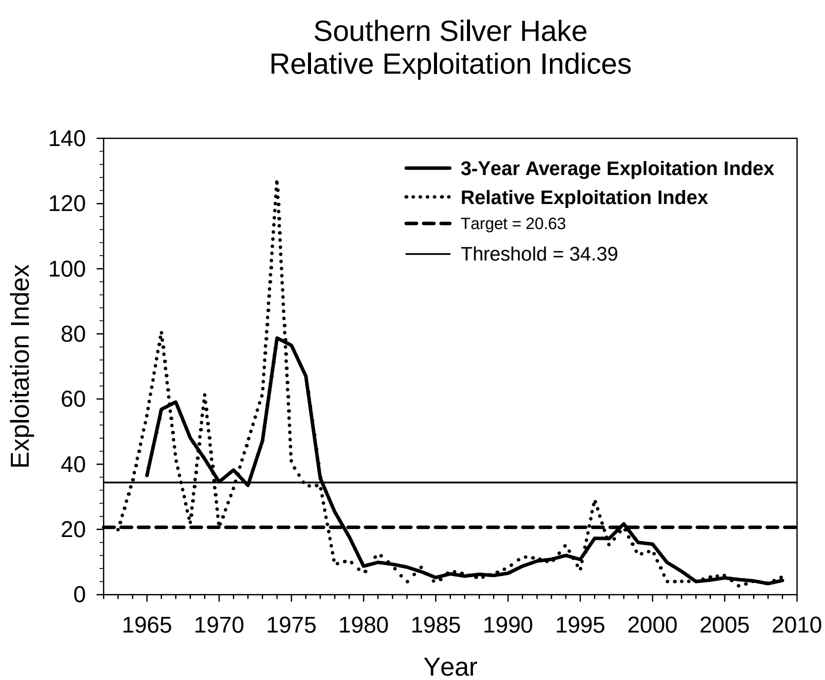
A2. Fall survey biomass (delta transformation) and current biomass reference points for the northern stock of silver hake.



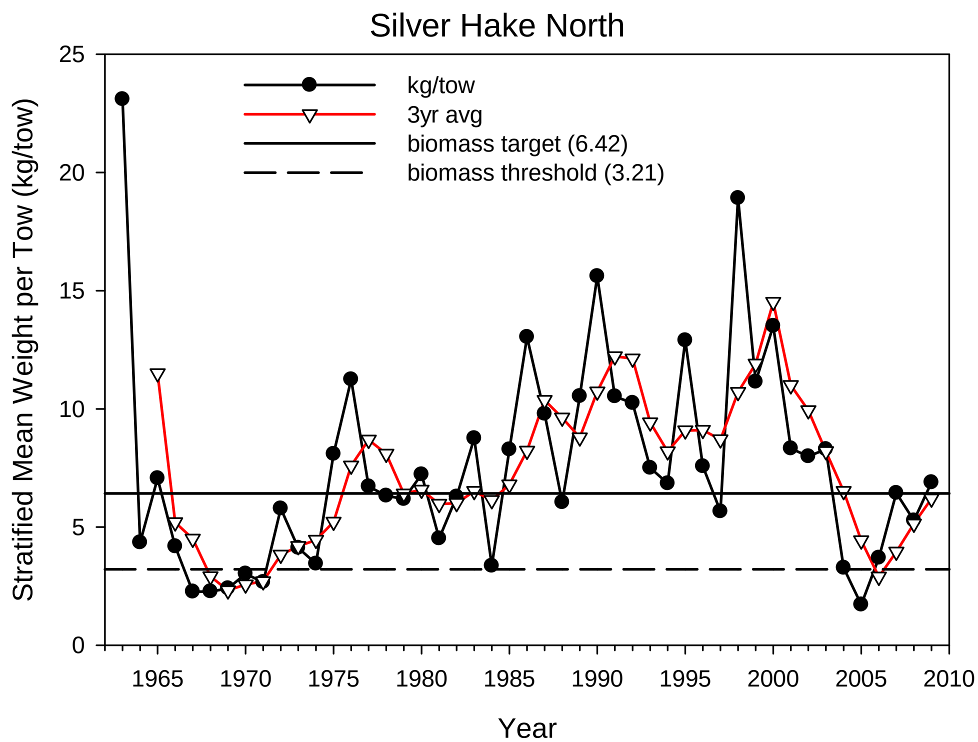
A3. Exploitation indices (delta transformation of fall survey) and current overfishing threshold for the northern stock of silver hake.



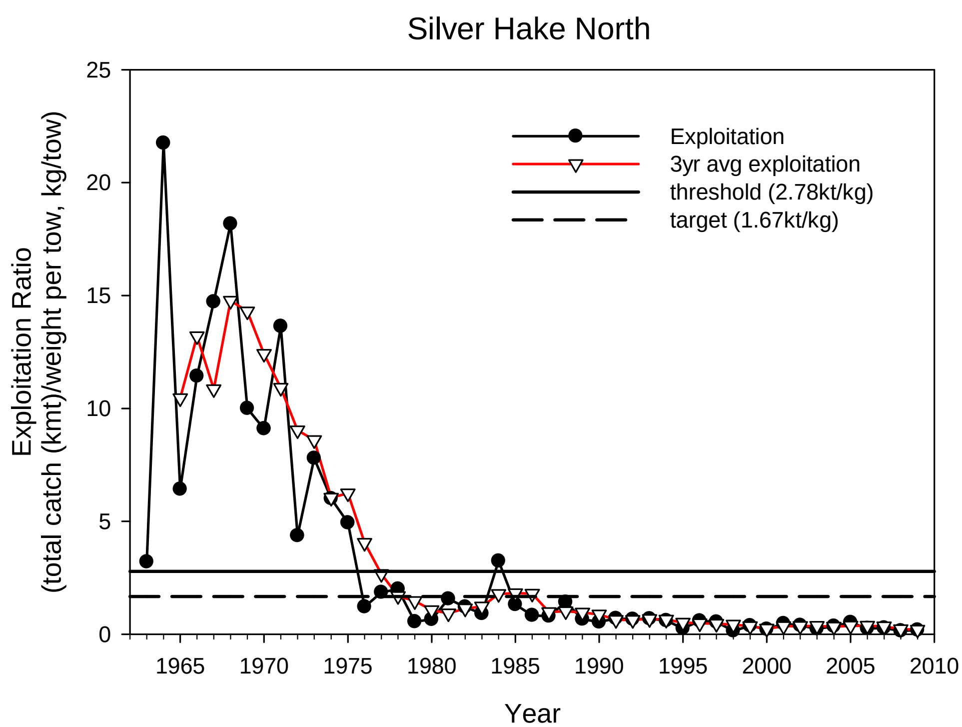
A4. Fall survey biomass (delta transformation) and current biomass reference points for the southern stock of silver hake.



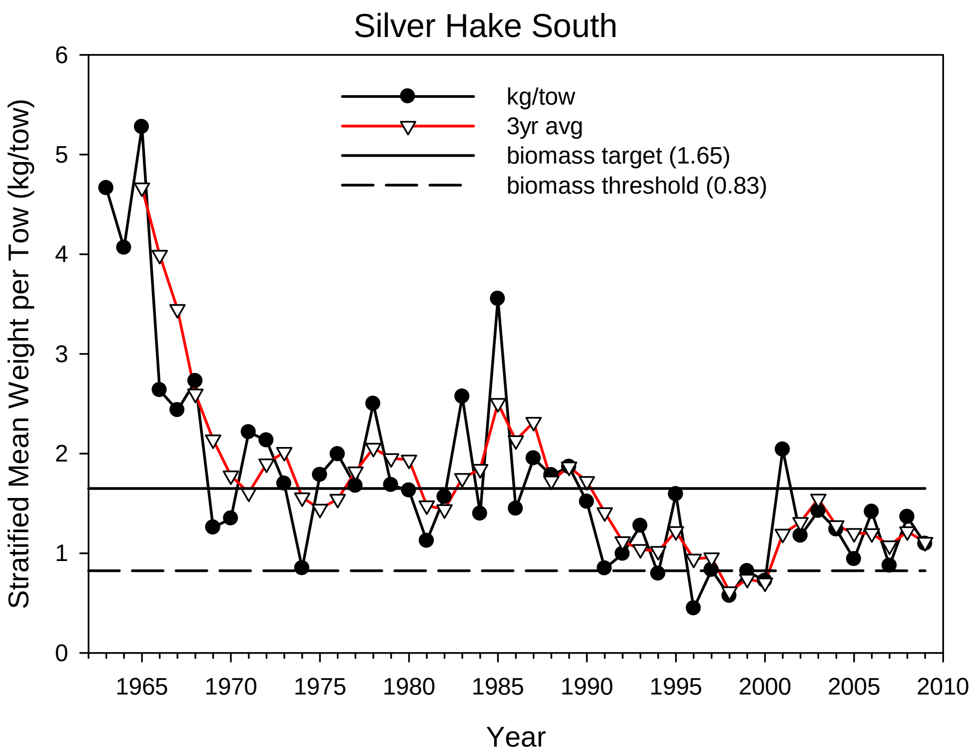
A5. Exploitation indices (delta transformation of fall survey) and current overfishing threshold (34.39) for the southern stock of silver hake.



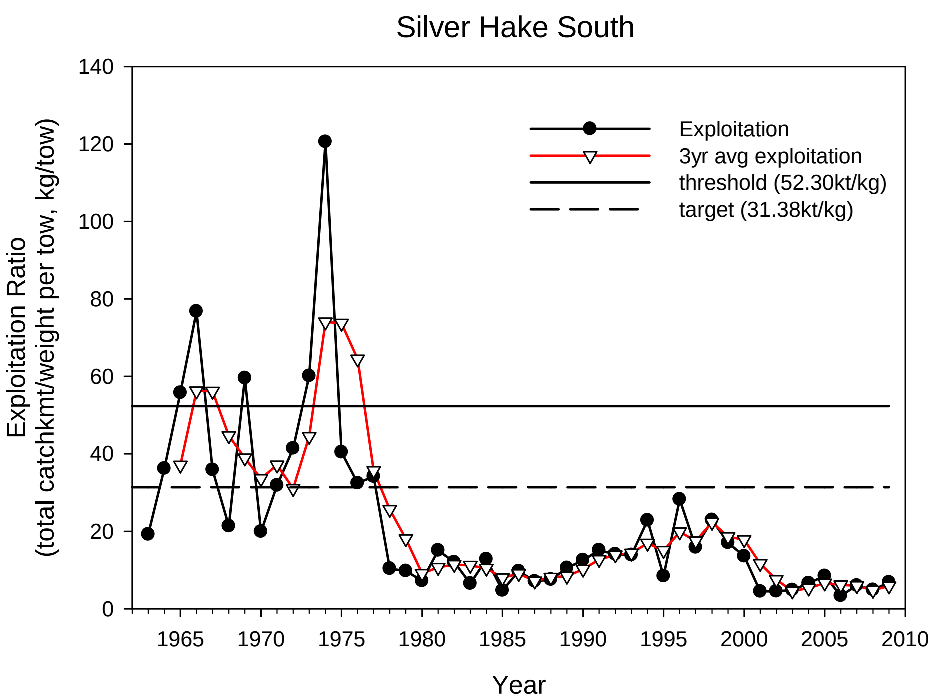
A6. Fall survey biomass (arithmetic mean) and newly proposed biomass reference points for the northern stock of silver hake.



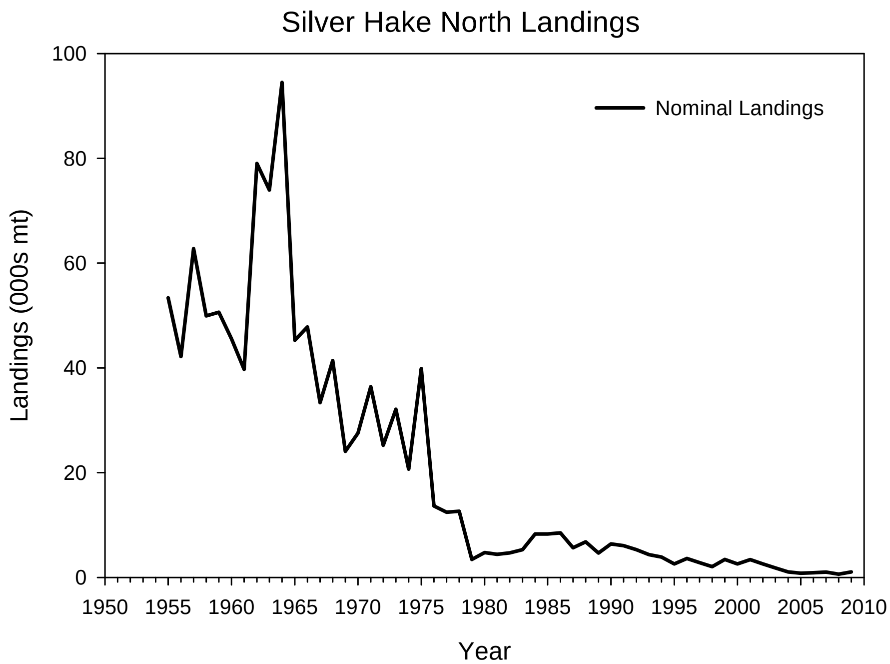
A7. Exploitation indices (ratio of catch to fall survey index) and newly proposed overfishing threshold and target for the northern stock of silver hake.



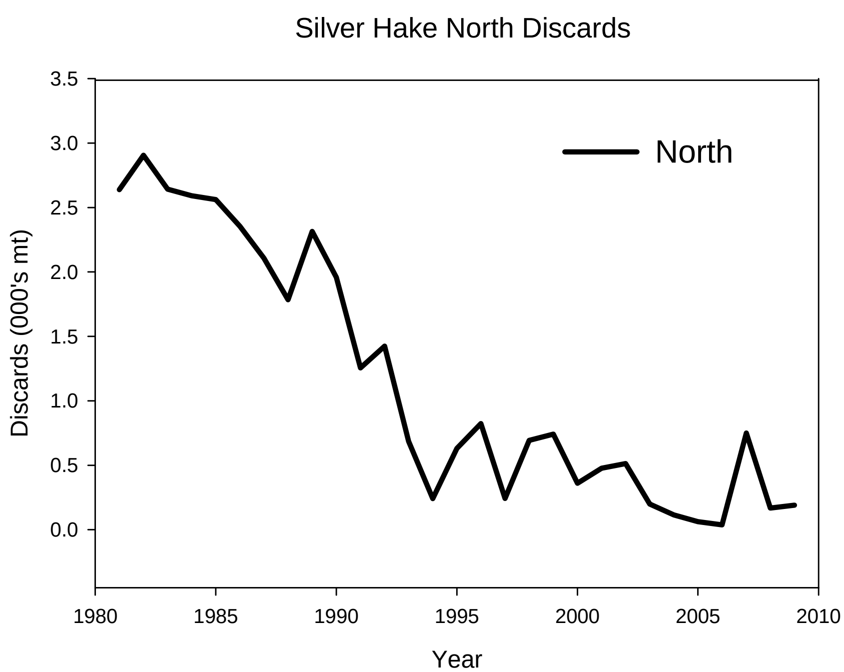
A8. Fall survey biomass (arithmetic mean) and newly proposed biomass reference points for the southern stock of silver hake.



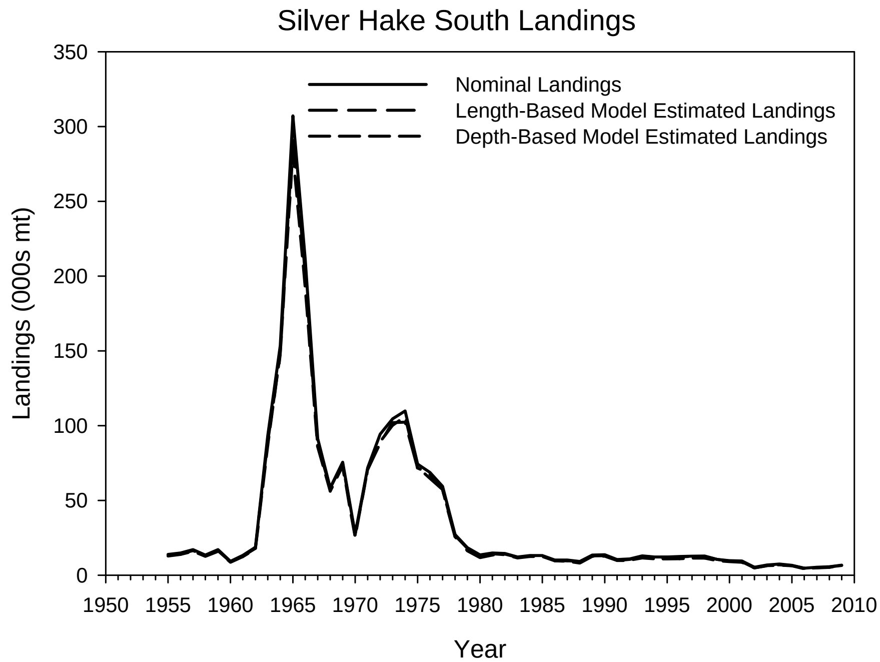
A9. Exploitation indices (ratio of catch to fall survey index) and newly proposed overfishing threshold and target for the southern stock of silver hake.



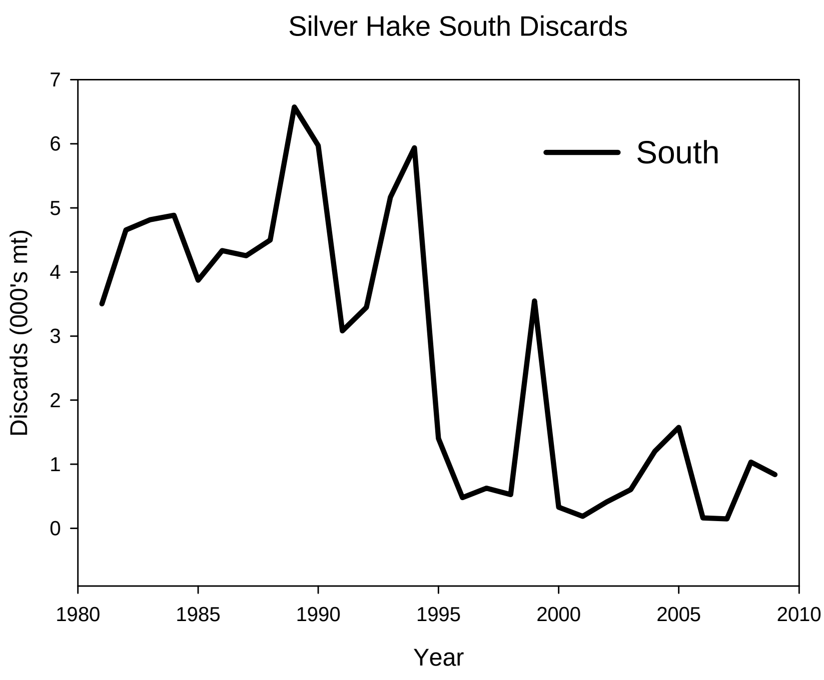
A10. Nominal landings of silver hake from the northern stock (000s mt).



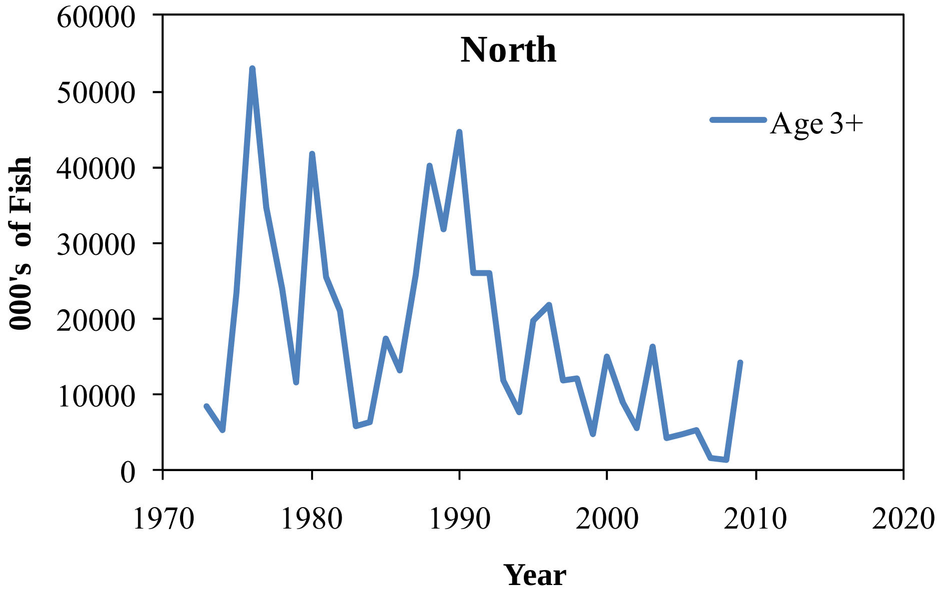
A11. Estimated discards if silver hake from the northern stock (000's mt).

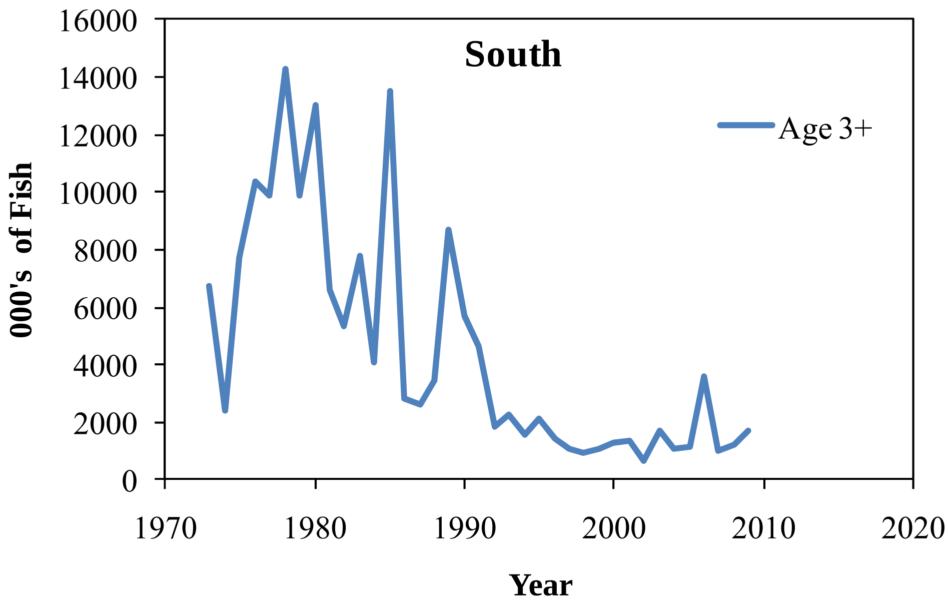


A12. Comparison of nominal landings of silver hake with length-based and depth-based model estimated landings (000s mt).

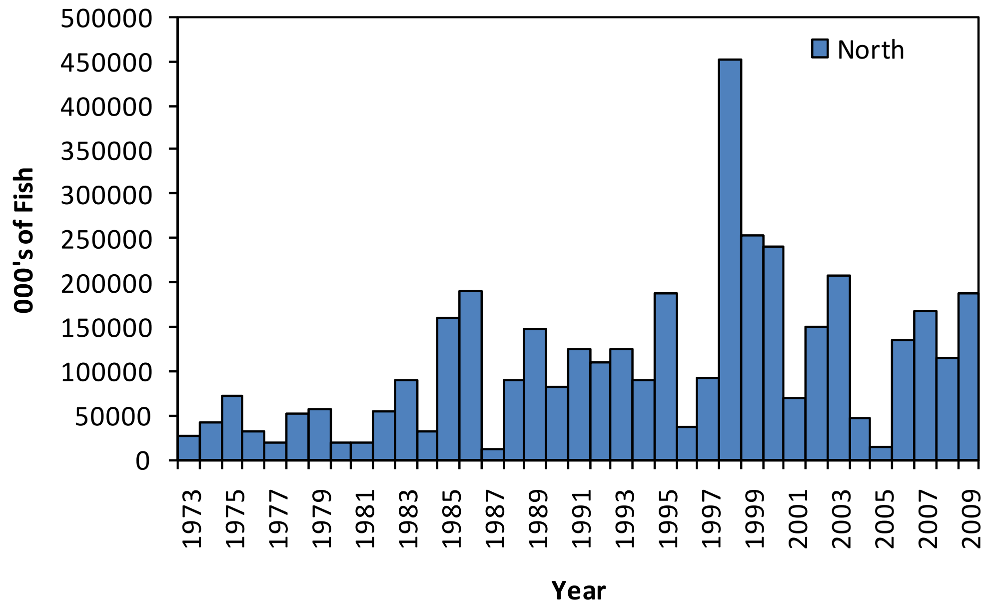


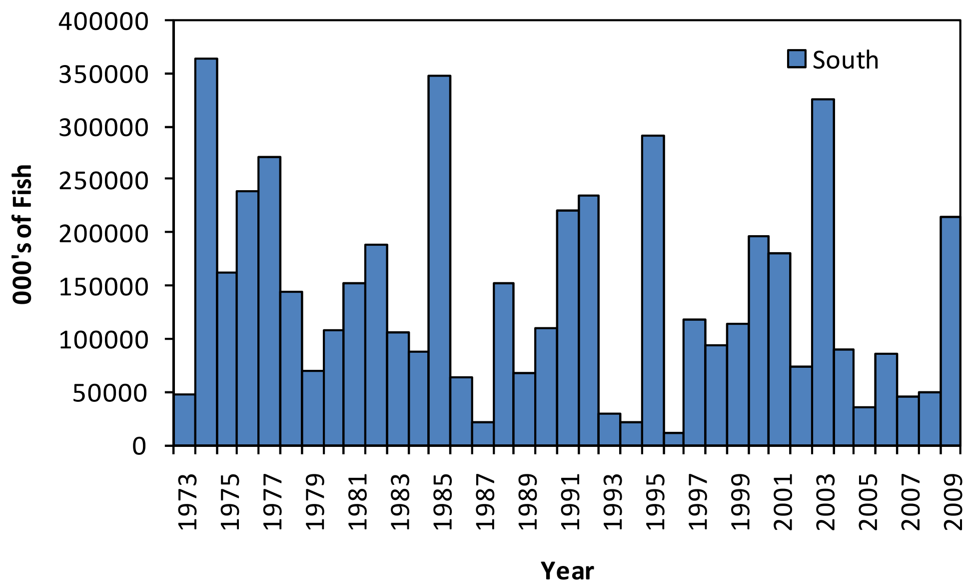
A13. Estimated discards of silver hake from the southern stock (000's mt).



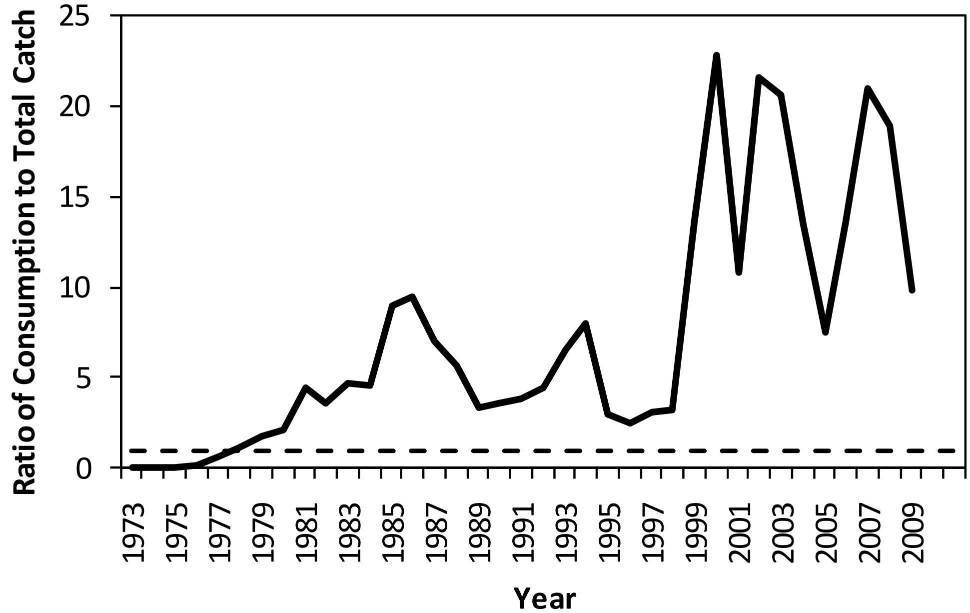


A14. NEFSC fall bottom trawl survey abundance of silver hake, based on swept area estimates in thousands of fish for age 3+ in the northern (top) and southern (bottom) management areas.

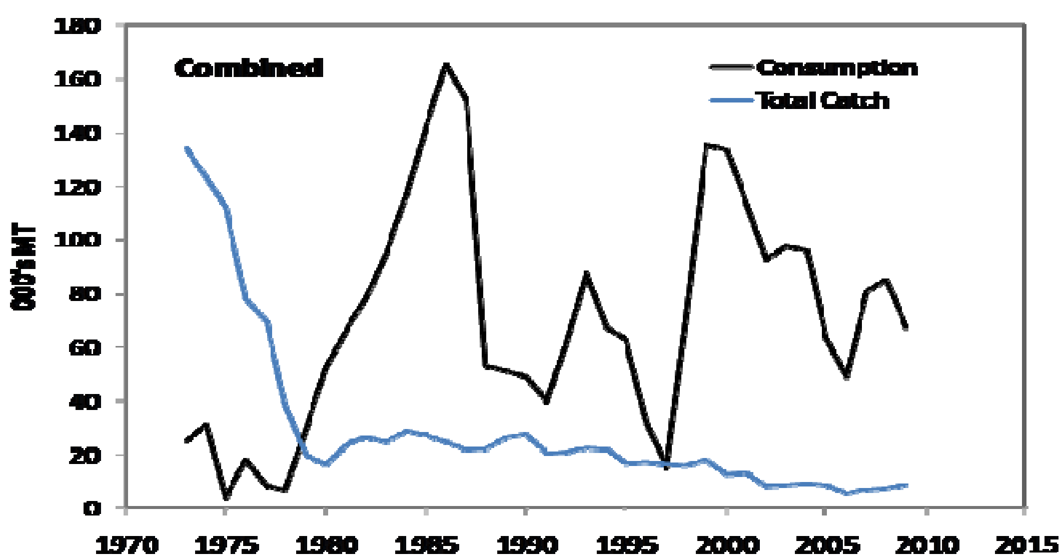




A15. Survey recruitment index (age 0's and 1's) in thousands of silver hake from the NEFSC bottom trawl survey for the northern (top) and southern (bottom) management areas.



A16. Ratio of silver hake consumption (by a subset of fish predators) to total catch of silver hake over time. Dashed line represents a ratio of one.



A17. Silver hake biomass consumed by major fish predators and total catch in the fishery for the north and south areas combined.

B. *LOLIGO* ASSESSMENT SUMMARY FOR 2010

State of Stock

Based on the current reference point, overfishing was not occurring in the longfin inshore squid (*Loligo pealeii)* stock in 2009 because the exploitation index (estimated with the methods of SARC-34) was 0.063, compared to $F_{THRESHOLD}$ (75^{th} percentile of exploitation indices during 1987-2009) which is 0.277. Currently, there is no biomass reference point for longfin inshore squid, and as a result, overfished status cannot be determined. The 2010 assessment concluded that the current *F* reference point approach is inappropriate for this lightly exploited stock.

Based on a new proposed biomass reference point from the 2010 assessment, the longfin inshore squid stock was not overfished in 2009, but overfishing status cannot be determined because no overfishing threshold was recommended. The biomass estimate, which is based on the two-year average of catchability-adjusted spring and fall survey biomass during 2008-2009, was 54,442 mt (80% CI = 38,452-71,783 mt). This is greater than the proposed $B_{THRESHOLD}$, currently estimated to be 21,203 mt (Figure B1). The stock exhibits very large fluctuations in abundance (from variation in reproductive success and recruitment) which is expressed as large inter-annual changes (2-3 fold) in survey biomass.

A new threshold reference point for fishing mortality was not recommended in the 2010 assessment because there was no clear statistical relationship between *Loligo* catch and annual biomass estimates during 1975-2009. Furthermore, annual catches were low relative to annual estimates of minimum consumption by a subset of fish predators. The stock appears to be lightly exploited. The 2009 exploitation index of 0.176 (catch in 2009 divided by the average of the spring and fall survey biomass during 2008-2009; 80% CI = 0.124-0.232) was slightly below the 1987-2008 median of 0.237 (Figure B2).

Forecasts

Forecasts of stock size were not possible because there is no accepted 2010 assessment model, and like most squid stocks, the short, sub-annual lifespan and semelparous life history (squid die after spawning) of this species result in rapid changes in stock size in response to environmental conditions (Hendrickson and Showell 2010; Dawe *et al.* 2007; Boyle and Rodhouse 2005).

Stock Distribution and Identification

Longfin inshore squid are distributed primarily in continental shelf waters located between Newfoundland and the Gulf of Venezuela (Cohen 1976; Dawe *et al*. 1990). In the northwest Atlantic Ocean, longfin squid are most abundant in the waters between Georges Bank and Cape Hatteras, North Carolina. Relative abundance in the Gulf of Maine is low in the fall, and annual occurrences there are infrequent during spring. However, abundance south of Cape Hatteras is unknown because the species' range overlaps with the congener, *L. pleii*, throughout the year and the two species cannot be distinguished using gross morphology (Cohen 1976). Catches of *L. pealeii* in NEFSC spring and fall surveys decline with depth and catches in seasonal depth transect surveys are also low in deeper waters (> 366 m); but the data for deeper waters were limited. The geographic distribution of the species is dependent on seasonal migration which is influenced by the environment (Dawe *et al*. 2007). Migrations are offshore and south during late fall through winter (generally October-March) and inshore and north during spring through fall (generally April-September). Some recent genetics studies indicate that the population between Cape Cod Bay, MA and Cape Hatteras, NC is a single stock (Garthwaite *et al*.1989; Herke & Foltz, 2002; Shaw *et al*. 2010), but Buresch *et. al.* (2006) concluded that there are multiple stocks.

Catch and Status Table: *Loligo* (wts in 000s mt)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009[4]	Min.[5]	Max[5]	Mean[5]
Landings	17.5	14.3	16.9	11.9	15.7	16.7	15.9	12.3	11.4	9.3	9.3	23.7	16.6
Discards	0.1	0.1	0.4	0.2	0.3	0.7	1.1	0.1	0.1	0.3	0.1	2.1	0.6
Catch	17.7	14.4	17.2	12.1	16.0	17.4	17.1	12.5	11.5	9.6	9.6	24.6	17.2
Jan-June	10.0	6.5	8.6	5.9	9.3	12.3	9.8	7.7	5.8	4.6	4.5	16.2	9.1
July-Dec	7.6	7.8	8.5	6.2	5.8	5.4	7.2	4.7	5.7	4.9	2.4	15.8	7.3
Quota[1]	15.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	19.0	15.0	44.0	28.1
Annual Biomass[2]	175.9	59.7	154.3	80.6	51.1	63.9	141.9	74.9	69.1	39.8	25.8	175.9	80.6
Sept-Oct Biomass	330.1	92.5	253.9	151.7	93.3	107.9	249.4	109.6	122.7	68.8	30.3	330.1	143.3
Mar-Apr Biomass	21.6	26.9	54.6	9.4	9.0	19.8	34.4	40.3	15.5	10.8	8.1	81.7	29.1
Annual Exploitation Indices[3]	0.10	0.24	0.11	0.15	0.31	0.27	0.12	0.17	0.17	0.13	0.10	0.66	0.27
Jan-June Exploitation Indices	0.46	0.24	0.16	0.63	1.04	0.62	0.29	0.19	0.38	0.43	0.16	1.26	0.48
July-Dec Exploitation Indices	0.02	0.08	0.03	0.04	0.06	0.05	0.03	0.04	0.05	0.07	0.02	0.16	0.07

[1] Annual quotas were allocated by trimester, during 2000 and 2007-2009, and by quarter during 2001-2006.
[2] Annual biomass is the annual mean of the q-adjusted biomass estimates from the NEFSC spring and fall surveys. The biomass estimates depend directly on the value for "q". Other values of "q" would provide different absolute values but the same trends.
[3] Annual exploitation indices are the annual catch divided by the annual biomass.
[4] The 2009 annual biomass and annual exploitation indices in the table were not used for stock status determination. Overfished stock status was based on the mean of the 2008-2009 annual biomass estimate and overfishing status would be based on the 2009 catch divided by the 2008-2009 annual biomass estimate.
[5] Min., max. and mean values are for the time period of the domestic fishery, 1987-2009, with the exception of the biomass estimates which include 1976-2009.

Landings

The U.S. squid fishery began in the late 1800s as a source of bait, and from 1928 to 1967, annual squid landings (including Northern shortfin squid, *Illex illecebrosus* landings) from Maine to North Carolina ranged from 500 to 2,000 mt (Lange and Sissenwine 1980). During 1967-1984, total landings of *Loligo* were predominately from an offshore, foreign fishery and averaged 20,130 mt, with a peak of 37,613 mt in 1973 (Figure B3). A small, seasonal domestic fishery operated inshore prior to 1987 and a domestic offshore fishery developed thereafter when the foreign fishery was eliminated. There is substantial uncertainty in the landings data prior to 1987 (Cadrin and Hatfield 1999). The onset and duration of the fisheries reflect the timing of squid migrations; generally offshore during October-March and inshore during April-September. Landings are highest in the offshore winter fishery and lowest in the inshore summer fishery. During 1987-2009, landings averaged 16,610 mt with a peak of 23,738 mt in 1989. Landings have been lower since in-season quotas were implemented in 2000, averaging 14,214 mt during 2000-2009. Landings declined between 2005 and 2009, from 16,720 mt to 9,307 mt.

Catches
Discards represented a small percentage of the annual catches during 1989-2009, averaging 3.4% of the landings, but were variable (0.4-11.2% of the landings during the same period). Discard estimates were imprecise (CVs ranged between 0.02 and 1.14 and averaged 0.53 during 1989-2009). Most of the discards occurred in the small-mesh (codend mesh size ≤ 64 mm) bottom trawl fisheries conducted in the Mid-Atlantic region (i.e., Statistical Areas > 600). Due to a lack of quantitative discard data prior to 1989, discards were assumed to be 3.4% of the landings during 1963-1988.

Total catches during the period of dominance by the foreign fleets (1967-1984) averaged 20,814 mt with a peak of 38,892 mt in 1973 (Figure B3). During the period of dominance by the domestic fishery, (1987-2009), catches averaged 17,181 mt with a peak of 24,566 mt in 1994. During 1988-1995, catches were generally at or above the 1987-2008 median (17,328 mt), but have generally been below the median since 2000, when in-season quotas were implemented and fishery closures occurred at least once per year. Catches declined after 2005 and reached their minimum since 1968 in 2009 (9,560 mt). During 1987-2009, catches in the January-June fishery were 1.4 times higher than the July-December catches on average.

Data and Assessment
A method used during the previous assessment (NEFSC 2002) was refined to assess the stock based on catchability-adjusted swept-area biomass, computed from NEFSC spring (March-April) and fall (September-October) bottom trawl surveys, and seasonal and annual exploitation indices. Catches were updated with new discard estimates for 1989-2009 and assumed discards of 3.4% (1989-2009 average discards) prior to 1989. In order to annualize the biomass estimates for the seasonal cohorts tracked by these surveys, annual averages of the fall and spring bottom biomass estimates were computed for 1976-2009.

Only daytime catches were used to compute the biomass estimates because the capture efficiency of bottom trawls is highest for *Loligo* during the day (Sissenwine and Bowman 1976; Brodziak and Hendrickson 1999). Daytime was defined based on the solar zenith (43-80º during fall surveys and 29-84º during spring surveys). Catchability (*q*) was determined using the median of composite "*q*-priors" computed using upper and lower bounds on effective tow distance, width of the area swept by the trawl, capture efficiency and a defined stock area.

The spring and fall biomass estimates represent mean biomass estimates of seasonal cohorts that are available to the January-June and July-December fisheries, respectively. Exploitation indices for the two fisheries were computed for 1987-2009 as January-June catch/March-April biomass and July-December catch/September-October biomass. Annual exploitation indices were also computed as the annual catch divided by the annual average of NEFSC spring and fall survey biomass estimates. Because of the rapid growth rates and overlapping cohorts, exploitation indices were calculated using all sizes of squid rather than just the recruited sizes (> 8 cm dorsal mantle length).

The NEFSC bottom trawl survey switched from the FRV *Albatross IV* to the FSV *Bigelow* in spring 2009. Survey data given here are in "*Albatross IV"* units.

Estimates of minimum consumption of *Loligo* by a subset of finfish predators (15 species) were computed seasonally and annually using data from NEFSC spring and fall surveys conducted during 1977-2009.

Estimates of spawning and non-spawning mortality were computed following Hendrickson and Hart (2006) and Caddy (1996).

Biological Reference Points

There are no existing biomass reference points for *L. pealeii* (NEFSC 2002; MAFMC 2009). The median of the annual averages of the spring and fall survey biomass during 1976-2008 is 76,329 mt. The stock appears to be lightly exploited, so assuming that the 1976-2008 median biomass estimate represents 90% of the stock's carrying capacity (*K*, see Special Comments), a new B_{MSY} target of 50% of *K* (0.50*(76,329/0.90) = 42,405 mt) is recommended. An appropriate biomass threshold is 50% of B_{MSY} (= 21,203 mt).

The current F_{MSY} proxy (0.31 per quarter or 1.24 per year) was calculated in the last assessment as the 75th percentile of quarterly exploitation indices during 1987-2000. The current fishing mortality reference point approach is not appropriate for the lightly exploited *Loligo* stock. New fishing mortality reference points are not recommended in this assessment due to the lack of evidence for the impacts of fishing on subsequent annual biomass estimates during 1975-2009. In addition, annual catches were low relative to annual estimates of minimum consumption by a subset of fish predators. The perception is that the stock is lightly exploited.

Exploitation indices

Annual exploitation indices were generally higher during 1987-1998 than during 1999-2009. Exploitation indices were higher during January–June than during July-December (Figure B4). The values of the exploitation indices depend directly on the value of "q". Other values of "q" would provide different absolute values but the same trends. The 2009 exploitation index (catch in 2009 divided by the average of the spring and fall survey biomass during 2008-2009 = 0.176, 80% CI = 0.124-0.232) is shown in Figure B2.

Recruitment

Given the complex life history characteristics of the species (see Forecasts and Special Comments sections) and lack of a suitable assessment model, recruitment could not be estimated.

Biomass

Squid species exhibit large inter-annual fluctuations in biomass (Boyle and Rodhouse 2005). Annual biomass (i.e., annual average of spring and fall survey biomass estimates) ranged between 25,806 mt and 175,894 mt during 1976-2009 (Figure B5A). In 2009, annual biomass was slightly below the median. Estimates of annual biomass relative to the proposed B_{MSY} threshold are shown in Figure B6.

During 1976-2009, spring biomass (median = 25,578 mt) were only one fifth of the fall biomass levels (median = 124,730 mt), suggesting that the productivity of the spring survey cohort may be much lower than the fall survey cohort (Figure B5B and C).

Ecosystem considerations

Natural mortality of this semelparous, subannual species (multiple cohorts per year with life spans shorter than one year), which is consumed by a wide range of cetacean, pinniped, avian, invertebrate and finfish predators, is very high; especially for spawners. Estimates of non-spawning mortality, 0.11 per week and spawning mortality, 0.19-0.48 per week, are very high. Minimum estimates of *Loligo* consumption by finfish showed high inter-annual variability, but were 0.8 to 11 times the annual catches during 1977-2009 (Figure B7). During 1987-2008, minimum consumption was much higher during the fall (median = 34,089 mt) than during the spring (median = 14,643 mt, Figure B6).

ABC considerations

Differences in productivity among cohorts could be considered when setting the annual Acceptable Biological Catch (ABC). The summer-hatched cohort has a faster growth rate than the winter-hatched cohort (Brodziak and Macy 1996) and the cohorts caught in the spring and fall surveys appear to have very different productivity and biomass. Exploitation indices for the January-June fishery (median = 0.315) are much higher on the less productive, spring survey cohort compared with the July-December fishery (median = 0.064) on the more productive fall survey cohort. The perceived differences in productivity could be due to different catchabilities in the spring and autumn surveys, as well as due to other factors.

The ecological importance of *Loligo* as prey for a wide range of species could also be considered. Alternatively, knowledge about consumption by selected predators could be used as a basis to "allocate" squid production between humans and other predators (e.g., fish).

During 1987-2009, when there was no foreign fishery, catches ranged between 9,560 mt in 2009 and 24,544 mt in 1989 and minimum consumption estimates ranged between 15,762 mt and 125,400 mt. for minimum estimates of total removals between 25,322 mt and 149,944 mt. These removals do not appear to have impaired productivity and higher catches may be sustainable.

Special Comments

Recruitment occurs throughout the year with seasonal peaks in overlapping "microcohorts" which have rapid and different growth rates (Brodziak and Macy 1996; Macy and Brodziak 2001) with substantial population turnover during the season (Guerra *et al*. 2010).

The duration of each seasonal cohort is about six months. Age data indicate that squid caught in the offshore, winter fishery (October-March) were hatched about six months prior, during the previous summer, and squid caught in the inshore, summer fishery (April-September) were also hatched, about six months prior, during the previous winter (Macy and Brodziak 2001). The NEFSC spring (March) and fall (September) surveys are conducted six months apart. Within a year, the relative abundance of the seasonal cohorts caught in these two surveys are correlated ($r = 0.53$). However, there is no correlation ($r < 0.10$) between relative abundance estimates in year t and year t+1, for either the spring or fall surveys, or between the fall surveys in year t and spring surveys in year t+1.

Loligo pealei attaches its egg masses to the substrate and fixed objects (MAFMC 2009). Fishing and spawning mortality occur concurrently during late spring through fall, when spawning *Loligo* and an unknown proportion of their egg masses are taken inshore, in weir and bottom trawl fisheries (Hatfield and Cadrin 2002). The locations of spawning sites at other times of the year are unknown.

The current approach to management with reference points, annual ABC, OFL, etc. is unlikely to be optimal for *Loligo* which live less than one year. It is likely to result in foregone yield in period of high productivity and may not protect the resource in periods of low productivity. For such a species adequate spawner escapement from each seasonal fishery is required to ensure sufficient recruitment in subsequent seasons, and in–season assessment and management is necessary to extract optimum yield.

Previous squid assessments (Pacific Fishery Management Council, 2002; NEFSC, 2003) have considered $F_{40\%}$ as a possible biological reference point. This approach has been used in other managed squid fisheries.

Survey biomass estimated in different years and in the spring and the autumn of the same year, largely correspond to different cohorts. Nonetheless, overfished status is determined using 2 year averages of annualized spring and autumn survey biomass estimates recognizing that a portion of the annual variability is due to factors other than changes in squid abundance, including estimation error. It is not clear if the spring and autumn biomass estimates should be averaged to obtain an annual estimate of if they should be summed.

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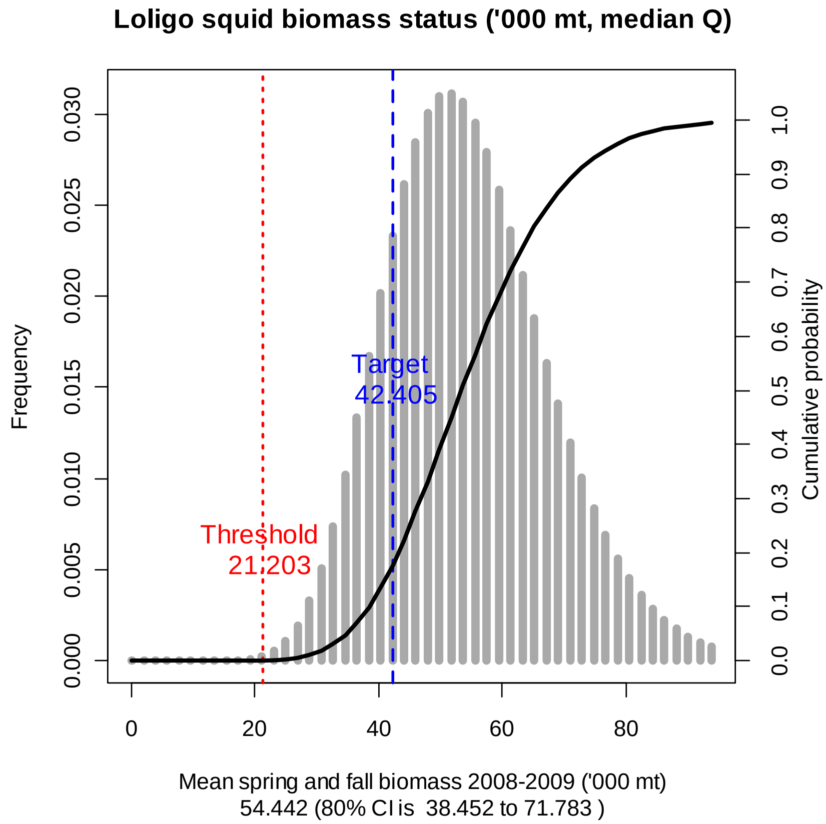
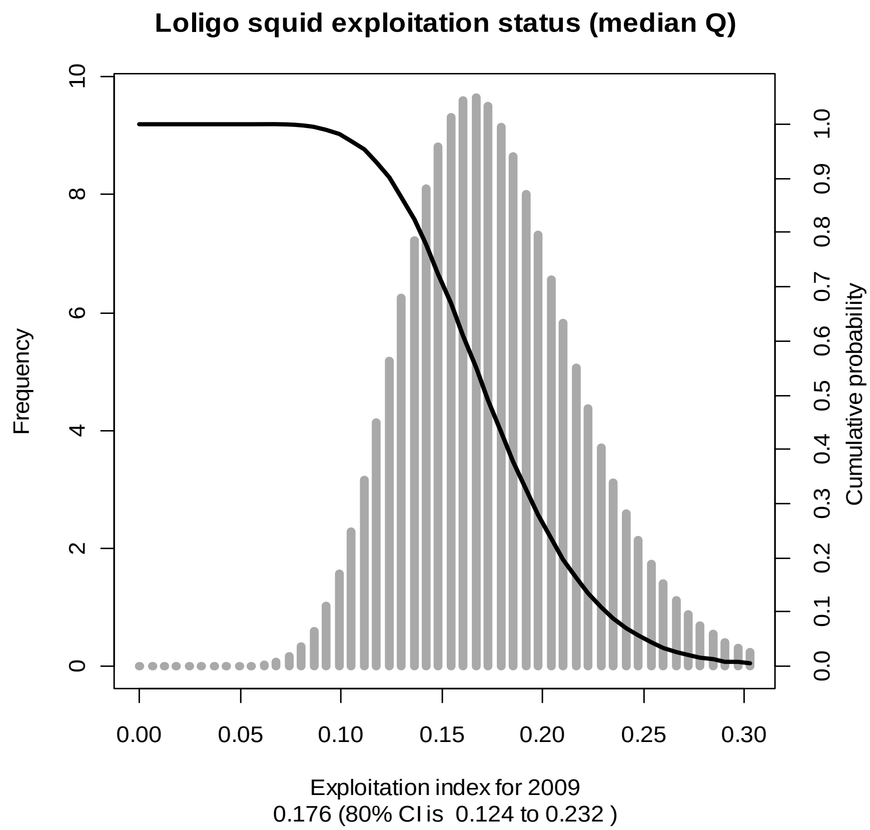
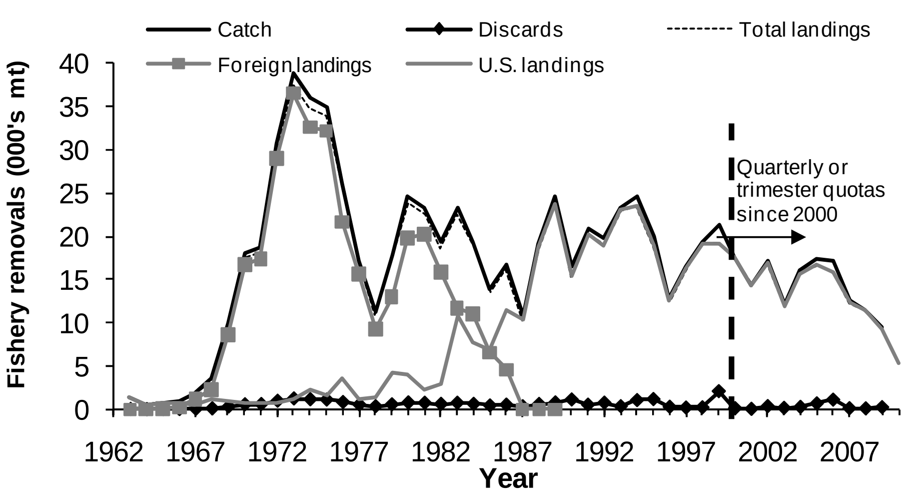


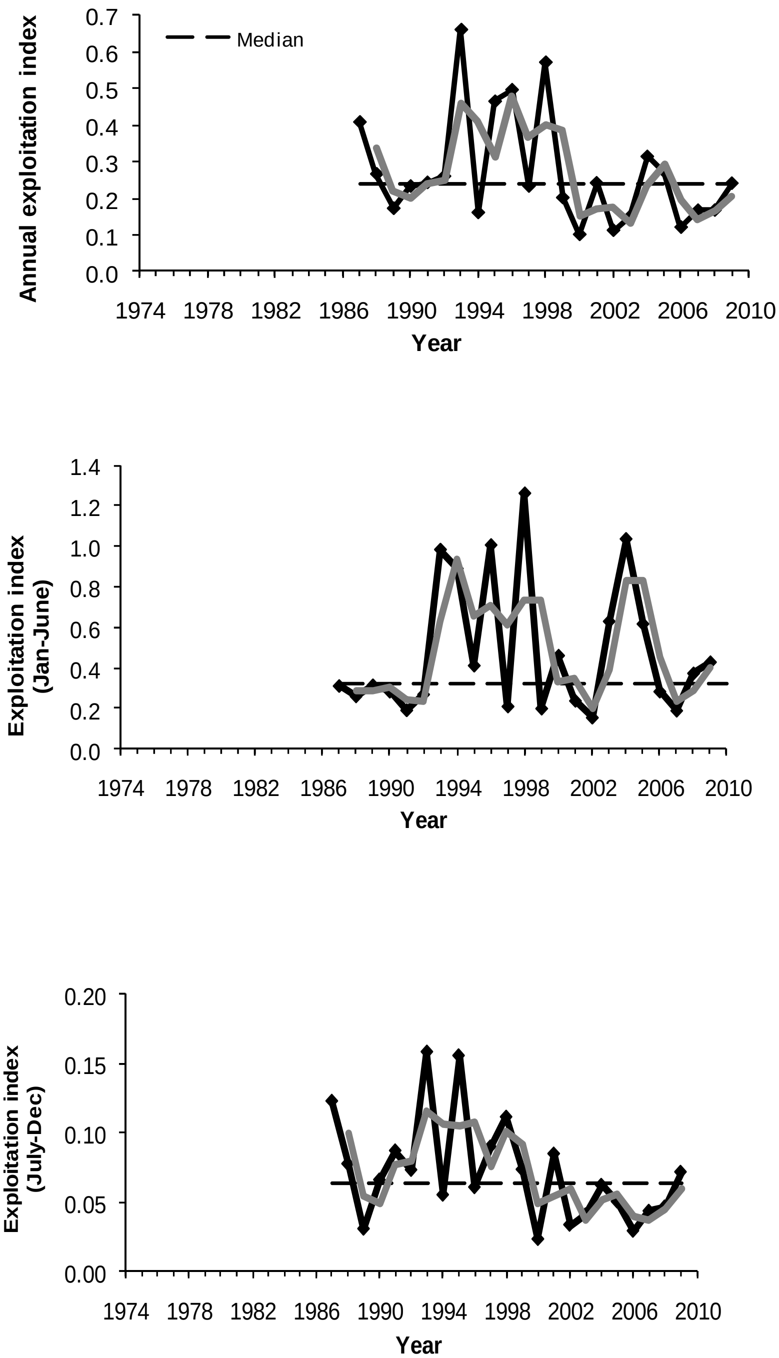
B1. *Loligo pealeii* biomass estimate (000s mt), spring and fall survey average for 2008-2009, shown as a probability distribution. Also shown are proposed biomass reference points.



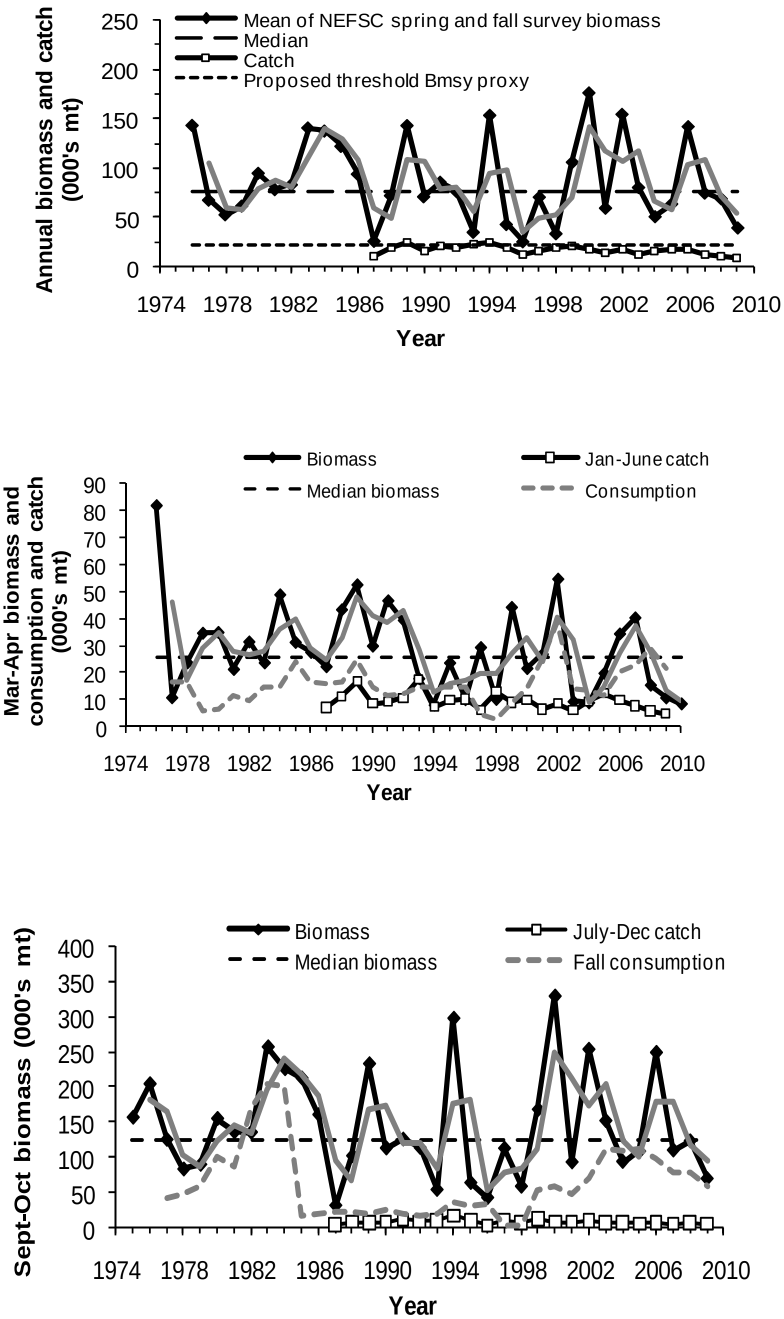
B2. *Loligo pealeii* exploitation index for 2009 shown as a probability distribution.



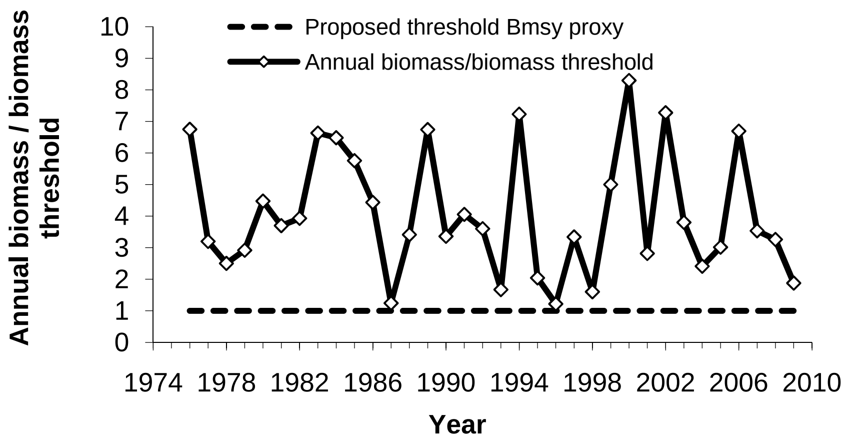
B3. Fishery removals of *Loligo pealeii*.



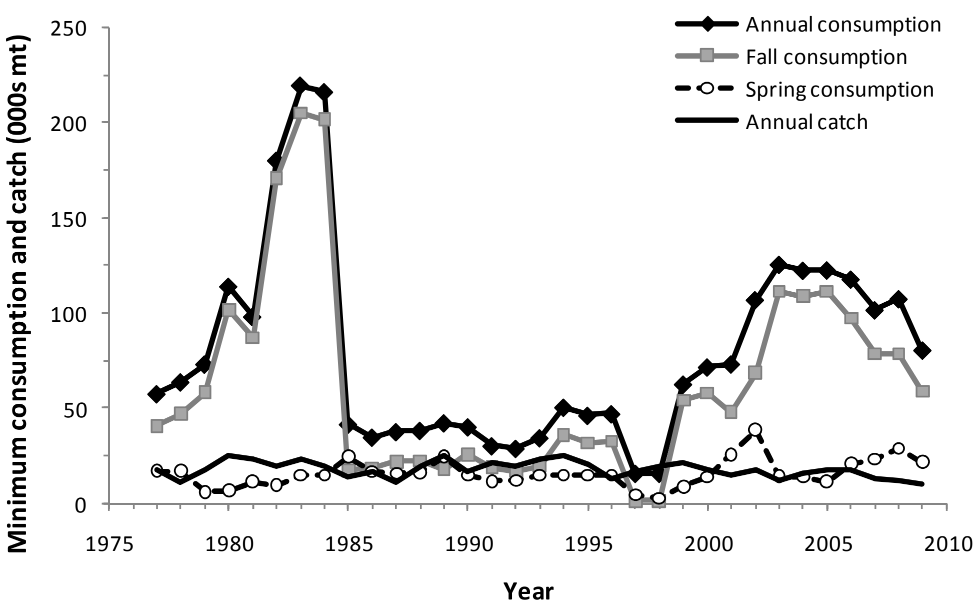
B4. Annual exploitation indices (annual catch / average of spring and fall biomass) of *Loligo pealeii* (A) and exploitation indices for the January-June fishery (January-June catch / March biomass) (B) and the July-December fishery (July-December catch / September biomass) (C). The grey lines represent the two-year moving averages which, in the top figure, indicates the 2009 value that would have been used for overfishing status determination if an $F_{THRESHOLD}$ had been defined.



B5. Annual estimates of *Loligo pealeii* biomass (annual averages of NEFSC spring and fall survey biomass) (A), March-April biomass and consumption in relation to January-June catch, and September-October biomass and consumption in relation to July-December catch (C). The grey lines represent the two-year moving averages which, in the top figure, indicates the 2009 value used for stock status determination.



B6. Annual biomass (average of annual spring and biomass / B_{MSY} threshold) in relation to the proposed biomass threshold (shown here as a relative value).



B7. Annual, spring and fall minimum consumption estimates of *Loligo pealeii*, for a subset of 15 finfish predators, in relation to annual catches of *L. pealeii.*

C. RED HAKE ASSESSMENT SUMMARY FOR 2010

State of Stock

Based on current biological reference points, the northern stock of red hake (*Urophycis chuss*) (Figure C1) is not overfished and overfishing is not occurring. The three year delta mean biomass index (Figure C2), based on the NEFSC fall bottom trawl survey for 2007-2009 (2.87 kg/tow), was above the management threshold level (1.6 kg/tow) and slightly below the target (3.1 kg/tow). The three year average exploitation index (landings divided by biomass index, Figure C3) for 2007-2009 (0.03) was below both the target (0.39) and the threshold (0.65).

Based on current biological reference points, the southern stock of red hake (Figure C1) is not overfished and overfishing status is unknown. The three year delta individual mean weight index (Figure C4), based on the NEFSC fall bottom trawl survey for 2007-2009 (0.10 kg/individual), is below the management threshold (0.12 kg/individual) but the three year average recruitment index (5.95 number/tow) is above the threshold value (4.72 number/tow).

Based on newly proposed biological reference points, the northern stock of red hake is not overfished and overfishing is not occurring. The three year arithmetic mean biomass index (Figure C5), based on the NEFSC spring bottom trawl survey for 2008-2010 (2.42 kg/tow), was above the proposed management threshold (1.27 kg/tow) and slightly below the target (2.53 kg/tow). The exploitation index (catch divided by biomass index, Figure C6) for 2007-2009 (0.103 kt/kg) was below the threshold (0.163 kt/kg).

Based on newly proposed biological reference points, the southern stock of red hake is not overfished and overfishing is not occurring. The three year arithmetic mean biomass index (Figure C7), based on the NEFSC spring bottom trawl survey for 2008-2010 (0.95 kg/tow), was above the proposed management threshold (0.51 kg/tow) and slightly below the target (1.02 kg/tow). The exploitation index (catch divided by biomass index, Figure C8) for 2007-2009 (1.150 kt/kg) was below the threshold (3.038 kt/kg).

Projections

Stochastic projections were not performed for this assessment. However, applying the threshold exploitation index F_{MSY} proxy to the three-year average biomass index (2008-2010) allows catches of 394 mt in the north and 2,897 mt in the south.

Catches

Nominal red hake commercial landings in the northern stock peaked at 15,000 mt in 1972 and 1973, followed by a sharp decline in 1977 corresponding to the departure of the distant water fleets (Figure C9). Landings then averaged 1,000 mt from 1977-1994, but declined to an average of only 100 mt through 2009. In the southern stock, nominal landings peaked at over 100,000 mt in 1965 with a second peak of 60,000 in 1972 (Figure C10). Landings then averaged 2,000 mt from 1977-1994, but declined to average 900 mt through 2009. Discards from the northern stock averaged 1300 mt in the early 1980s, declined to about 250 mt from 1995-2000 and have averaged 100 mt through 2009 (Figure C11). Discards from the southern stock averaged 4,000 mt in the 1980s, declined to about 1,000 mt from 1995-2000 and have averaged 700 mt through 2009 (Figure C12). Recreational landings have been relatively small with averages of 300 mt in the south compared to less than 3 mt in the north (Figure C13).

Catch data are a major source of uncertainty for this assessment because of mixed reporting of landings of red and white hake and uncertain identification to species by observers. Therefore, a length-based model was developed to estimate the proportion of red hake in the total hake catch (red and white hake combined). The model estimates for the northern stock area were generally lower than the nominal and the large peak in landings in the 1970s is eliminated (Figure C9). The landings for the southern stock area were also lower but the trend was similar (Figure C10). The complete change in trend in the north was not considered acceptable, so the length-based split was not used, and the nominal catch was used in the assessment.

From 1994 to 2009, landings for bait in the north have averaged 50% of the reported landings and ranged from one percent of the reported landings early in the time series to five times the reported landings in more recent years. In some years, less than three vessels reported bait landings on VTRs. Therefore, bait landings cannot be tabulated separately.

Catch and Status Table (weights in mt): Red Hake

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Max[1]	Min[1]	Mean[1]
Nominal Landings[2]														
North														
US	197	222	275	210	103	96	96	69	52	85		3792	52	746
DWF[2]												14926	2	4704
Rec	0.06	0.48	0.28	0.13	0.02	0.02	0.05	0.21	0.22	0.43		30.89	0.00	3
Total	197	223	275	210	103	96	96	69	52	85		15290	52	2160
South														
US	1417	1469	663	623	588	356	375	470	580	575		32622	356	4054
DWF[3]												103937	50	21258
Rec	44	24	10	18	10	55	53	20	74	100		971	10	275
Total	1462	1492	673	641	599	411	429	489	653	674		108016	411	14533
Combined														
US	1614	1691	938	832	691	452	471	539	632	659		32910	452	4799
DWF[3]												108627	50	24198
Rec	44	24	11	18	10	55	54	20	74	100				
Total	1659	1715	949	850	701	507	524	559	706	760		113594	507	16693
Nominal Discards														
North	55	135	101	88	57	57	181	127	59	95		1460	55	552
South	3889	3910	2968	3389	3313	3462	674	1545	814	869		4292	674	2735
Combined	3944	4045	3069	3476	3371	3519	855	1673	873	964		5752	855	3287
Catch Used in Assessment[4]														
Northern	252	358	376	297	160	153	277	197	112	180		15290	112	2480
Southern	5351	5403	3642	4029	3912	3873	1103	2035	1467	1543		108016	1103	16119
Combined	5602	5760	4018	4326	4072	4026	1380	2231	1579	1724		113594	1380	18599
North														
Fall Survey Delta Biomass	6.50	5.38	6.47	3.88	1.66	1.27	3.68	2.41	3.56	2.65		6.50	0.26	2.86
3-Year Average Fall Survey Delta Biomass	4.96	5.07	6.12	5.24	4.00	2.27	2.20	2.45	3.21	2.87		6.12	0.45	2.84
Landings/Fall Delta Biomass	0.02	0.03	0.03	0.04	0.04	0.06	0.04	0.04	0.01	0.03		5.00	0.01	0.81
South														
Individual Fall Mean Weight/Tow[5]	0.16	0.15	0.10	0.09	0.06	0.08	0.11	0.06	0.12	0.11		0.22	0.04	0.13
3-Year Average Ind. Mean Wt/Tow	0.12	0.11	0.13	0.11	0.08	0.08	0.09	0.09	0.10	0.10		0.21	0.08	0.13
Fall Recruitment[6]	0.50	10.18	5.71	4.45	4.78	7.60	5.63	10.33	3.14	4.38		29.86	0.50	5.14
3-Year Average Recruitment	4.67	7.72	5.46	6.78	4.98	5.61	6.00	7.85	6.37	5.95		11.82	1.11	5.26
Biomass (Spring Survey kg/tow)														
North	3.19	3.58	4.46	1.00	1.77	1.10	0.91	2.06	3.49	1.75	2.02	6.35	0.54	2.43
South	0.42	0.64	0.54	0.21	0.15	0.38	0.38	0.86	0.47	1.34	1.04	7.65	0.15	1.61
Combined	1.51	1.80	2.08	0.52	0.79	0.66	0.59	1.33	1.66	1.50	1.66	5.65	0.52	1.94
3-Year Average Biomass (Spring Survey kg/tow)														
North	2.68	3.03	3.74	3.01	2.41	1.29	1.26	1.36	2.15	2.43	2.42	4.12	0.61	2.48
South	0.36	0.51	0.54	0.46	0.30	0.25	0.30	0.54	0.57	0.89	0.95	5.09	0.25	1.64
Combined	1.27	1.50	1.80	1.47	1.13	0.66	0.68	0.86	1.19	1.50	1.61	4.21	0.66	1.97
Relative Exploitation Rate (Catch/Spring Biomass)														
North	0.079	0.100	0.084	0.298	90	0.140	0.303	0.096	0.032	0.103		9.631	0.032	1.198
South	12.652	8.417	6.719	19.597	25.335	10.298	2.902	2.373	3.099	1.150		49.360	0.841	8.171

[1]Nominal Landings data based on 1960-2009 (mt). Length-Based Model Estimated Landings based on 1964-2009. Commercial fishery discard means from 1981-2009. Fall survey north data based on 1963-2009. Fall survey south data based on 1967-2009. Spring survey data based on 1968-2010. Relative exploitation rate (catch/spring biomass) based on 1980-2009.

[2]Nominal landings from 1994-2009 include landings sold as bait.

[3]Foreign landings are for NAFO Areas 5 and 6.

[4]Catch is nominal landings plus nominal discards.

[5] Mean weight of an individual fish from the NEFSC fall survey.

[6] Number of fish < 25 cm from the NEFSC fall survey.

Stock Distribution and Identification

Red hake is a demersal gadoid species distributed from the Gulf of St. Lawrence to North Carolina, and is most abundant from the western Gulf of Maine through Southern New England waters (Bigelow and Schroeder 1953). Red hake are separated into northern and southern stocks for management purposes. The northern stock extends from the Gulf of Maine to Northern Georges Bank region, while the southern stock extends from the Southern Georges Bank to Mid-Atlantic Bight region. Red hake stock structure was determined by considering distribution, homogeneous maturity, and differences in growth. There was no strong biological evidence to support either a separate or combined assessment. Analysis of otoliths from red hake captured in the northwestern and eastern part of the Bay of Fundy (Gulf of Maine) varied from the otolith morphology for red hake captured elsewhere and had intermediate characteristics with white hake, suggesting the possible existence of hybridization in that area (Penttila and Dery 1988).

Data and Assessment

Information used in the 2010 assessment include data from the NEFSC surveys, as well as commercial fishery data from vessel trip reports, dealer landings records and on-board fishery observers through 2009. The NEFSC bottom trawl survey switched from the FRV *Albatross IV* to the FSV *Bigelow* in spring 2009. Survey data given here are in "*Albatross IV"* units.

Although some statistical catch at length models (SCALE and SS3) were applied, model diagnostics were not adequate for stock status determination or for the provision of fishery management advice. Therefore, the assessment is based on the spring survey indices and exploitation indices from each area.

Examination of the effect of using the delta transformation on the variability of red hake survey indices indicated that the transformation did not reduce the variance. The delta transform and was very sensitive to the treatment of zero weight tows which occurred when the weight of fish was less than 0.1 kg prior to 2001. Therefore, the arithmetic mean is considered a better option for assessment purposes.

Biological Reference Points

The current overfishing definition for northern red hake reads as follows:

> *The northern stock of red hake is overfished when the three-year moving average of stock biomass, derived from the fall survey, is below* ***1.6 kg/tow****. If an analytical assessment is available for northern red hake, then the three-year moving average will be replaced with the terminal year biomass estimate and compared with the biomass reference points.*
>
> *Overfishing occurs when the ratio between catch and survey biomass exceeds* ***0.65****, the proxy for F_{MSY}. When biomass is less than 3.1 kg/tow (the biomass target), the stock is overfished when fishing mortality is above a rate that declines linearly to zero when biomass equals the minimum biomass threshold (1.6 kg/tow).*

The current overfishing definition for southern red hake reads as follows:

The southern stock of red hake is in an overfished condition when the three-year moving average weight per individual in the fall survey falls below the 25th percentile of the average weight per individual from the fall survey time series 1963-1997 (0.12) AND when the three-year moving average of the abundance of immature fish less than 25 cm falls below the median value of the 1963-1997 fall survey abundance of fish less than 25 cm (4.72).

In previous SAFE Reports, the Whiting Monitoring Committee (WMC) noted problems associated with the overfishing definition for southern red hake. Although the current definition is intended to identify overfished (i.e. low biomass) stock conditions, it is a better indication of overfishing (high exploitation rate). The WMC recommended that the overfishing definition for the southern stock of red hake be revisited.

New proposed BRPs for both northern and southern red hake stocks are as follows:

> *Red hake is overfished when the three-year moving arithmetic average of the spring survey weight per tow (i.e., the biomass threshold) is less than one half of the B_{MSY} proxy, where the B_{MSY} proxy is defined as the average observed from 1980 – 2010. The current estimates of $B_{THRESHOLD}$ for the northern and southern stocks are 1.27 kg/tow and 0.51 kg/tow, respectively.*
>
> *Overfishing occurs when the ratio between catch and spring survey biomass exceeds 0.163 kt/kg and 3.038 kt/kg, respectively, derived from AIM analyses from 1980-2009.*

Applying the F_{MSY} proxy to the B_{MSY} proxy allows for an MSY of 412 mt for the northern stock and 3,086 mt for the southern stocks. Catch per tow is in "Albatross" units (see Data and Assessment section).

The 80% confidence interval around the F_{MSY} proxy for the north is 0.062 - 0.240 kt/kg/tow (Figure C14), and for the south is 2.240 - 3.700 kt/kg/tow (Figure C15).

Fishing Mortality

For the northern stock, exploitation indices were derived for two time series. The fall survey shows very high exploitation in the 1960s and early 1970s, followed by a drop to low values from 1977 through the rest of the time series (Figure C3). This coincides with the departure of the distant water fleet. The second time series for exploitation was derived using the spring survey and shows a similar trend (Figure C6).

There is only one time series for the southern stock and it is based on the spring survey. The same peak is evident in the 1960s-1970s followed by a decline (Figure C7). However, exploitation generally increased from the late 1970s through 2005 (Figure C8). Exploitation declined since 2005.

Recruitment
Recruitment estimates from the southern stock have been variable with increased recruitment in the last decade (Figure C4).

Stock Biomass
For the northern stock, total biomass indices were derived for two time series. The fall survey increased from 1970 through 2002 followed by a decline through 2005 (Figure C2). The spring survey increased from 1970 through 1980, but declined through 1990, increased again through 2002 and then was consistent with the fall survey (Figure C5).

For the southern stock, the spring survey increased from 1970 through 1980, but declined through 2005, with a slight increase through 2009 (Figure C7).

Ecosystem Considerations
Estimates of minimum annual consumption of red hake by a subset of 12 finfish predators were computed using data from NEFSC spring and fall surveys during 1977-2009. Consumption was approximately 5 thousand mt per year during the late 1970s to late 1990s. These removals have averaged approximately 10 thousand mt in the 2000s (Figure C16). Estimates of red hake consumed by the subset of fish predators in this study were compared to total catch (Figure C16). Catch and minimum estimates of consumption were approximately equal for the early part of the time series. More recently, consumption has been the dominant source of removals, averaging approximately five times the fishery catch (Figure C17).

Special Comments
Some juvenile red hake inhabit shells of dead sea scallops. Abundance of scallop shells might have had an impact on the abundance of red hake. Prior to the recovery of the scallop stock, there may not have been enough available habitat to protect juvenile red hake (Steiner *et al* 1992). This is more related to the southern stock because the northern stock is likely to be able to find shelter in the rocky habitat of the Gulf of Maine. The recovery of scallops may have contributed to recent red hakes increases in the south, and scallop shell availability is probably not currently limiting.

The scientific information available on red hake stock structure included distribution, maturity, and growth rate. There was no strong biological evidence to support either a separate or combined red hake assessment.

Both the fall and spring surveys were examined, and the spring survey had more consistency in the AIM analysis. The confidence intervals for the relative exploitation indices were also smaller. Therefore, the spring survey data were used for reference point estimation.

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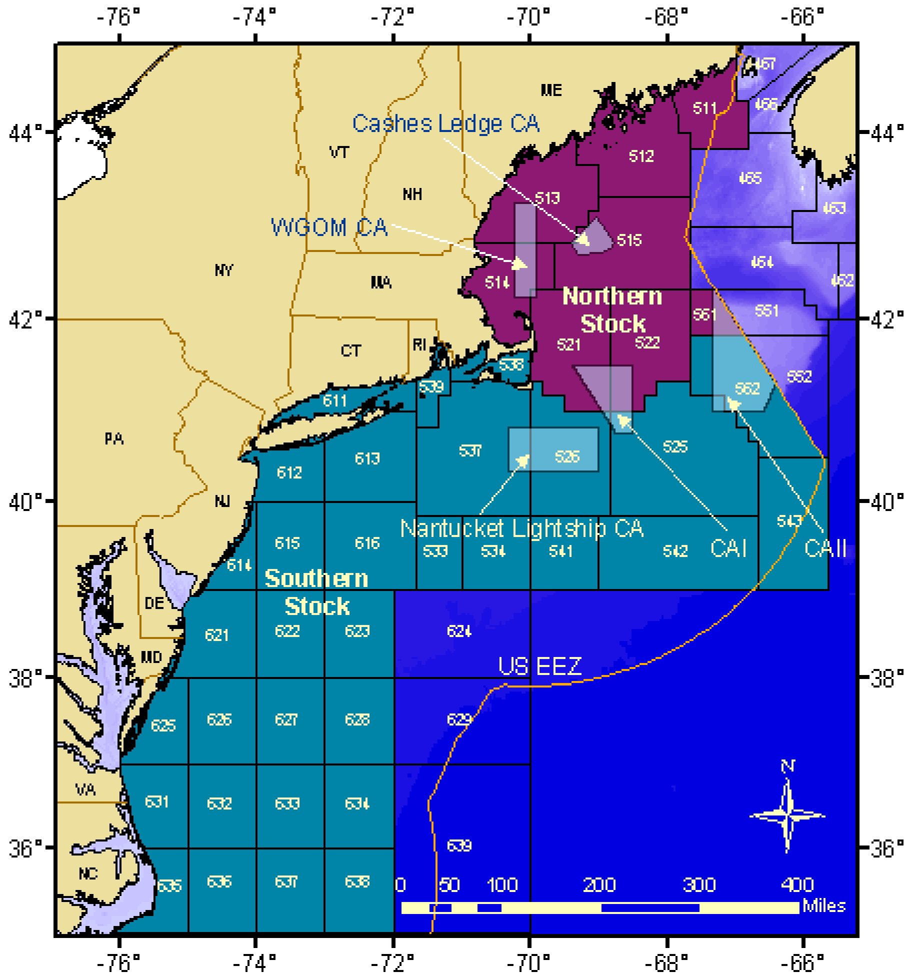
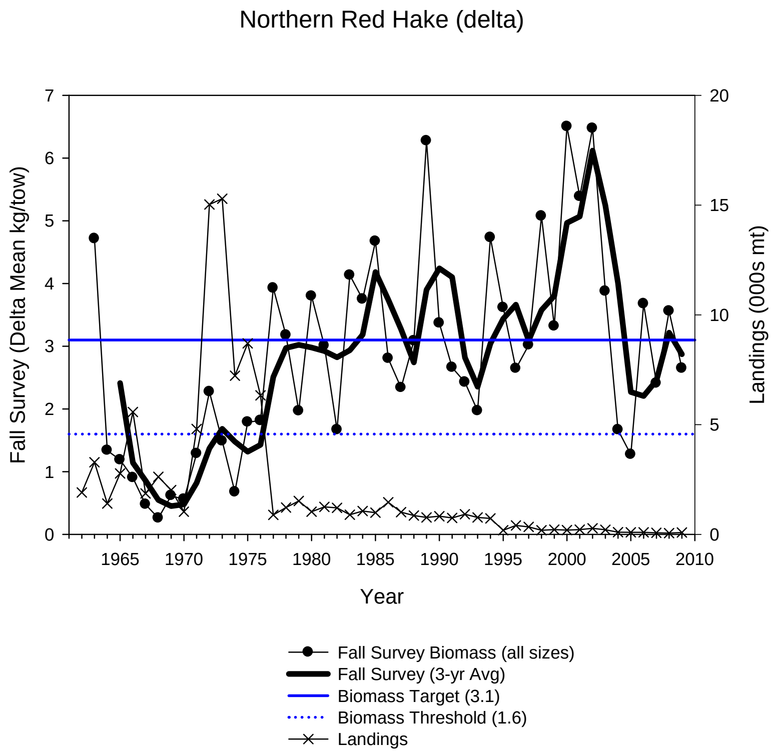
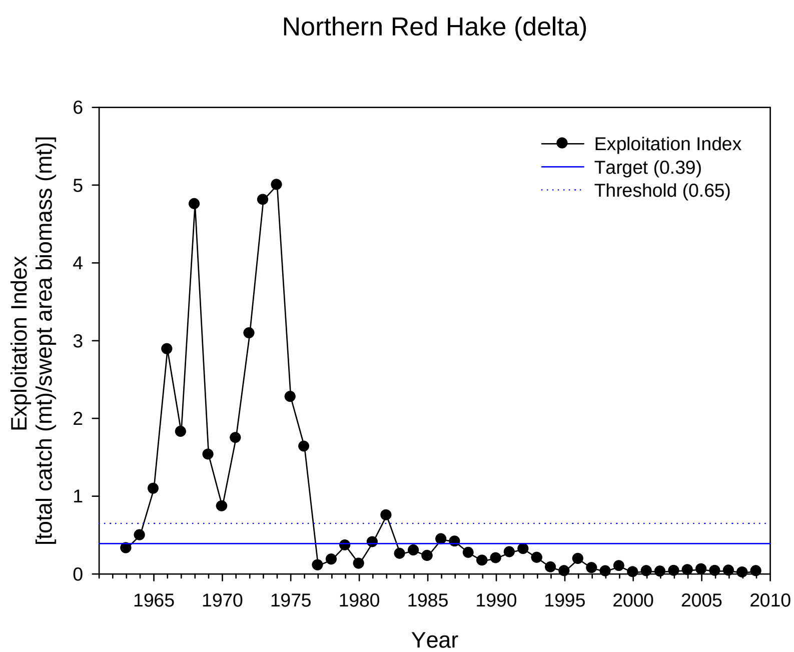


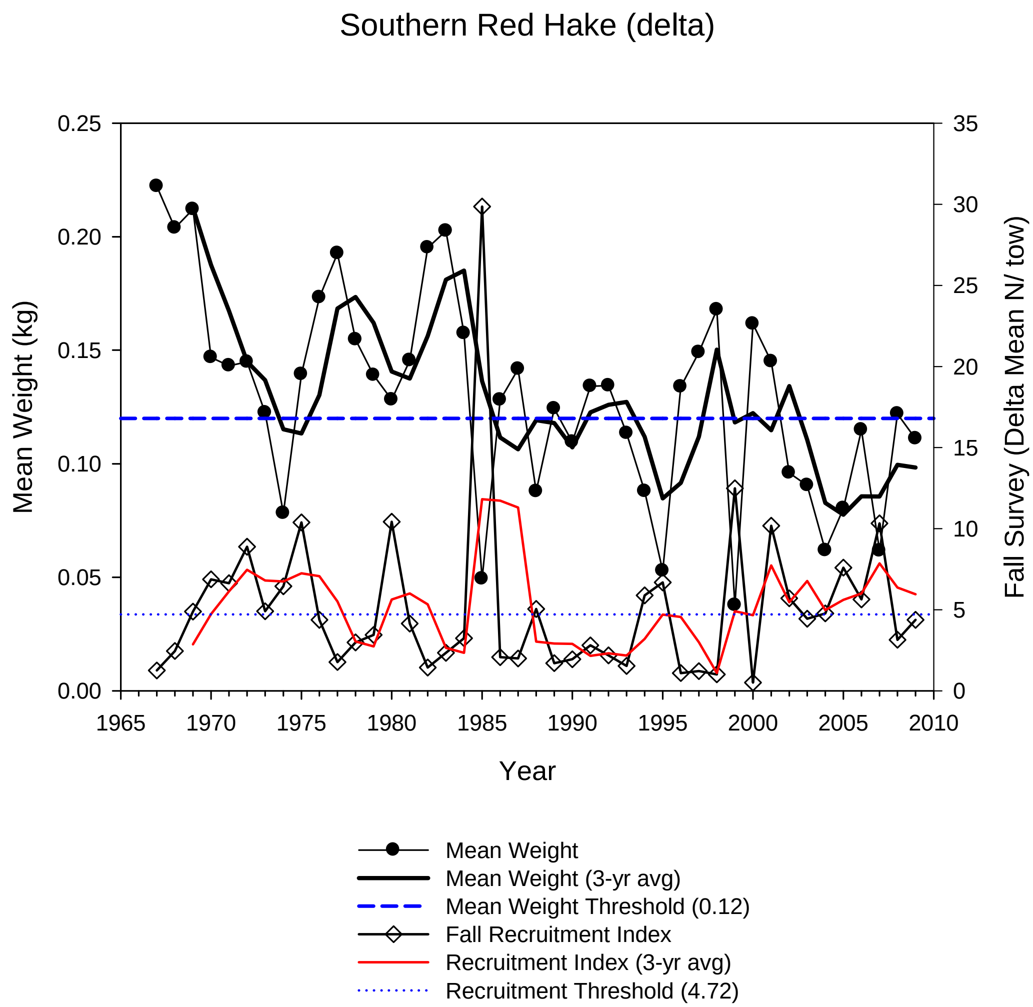
C1. Statistical areas used to define the northern and southern red hake stocks. Areas 464 and 465 are also included in the northern stock.



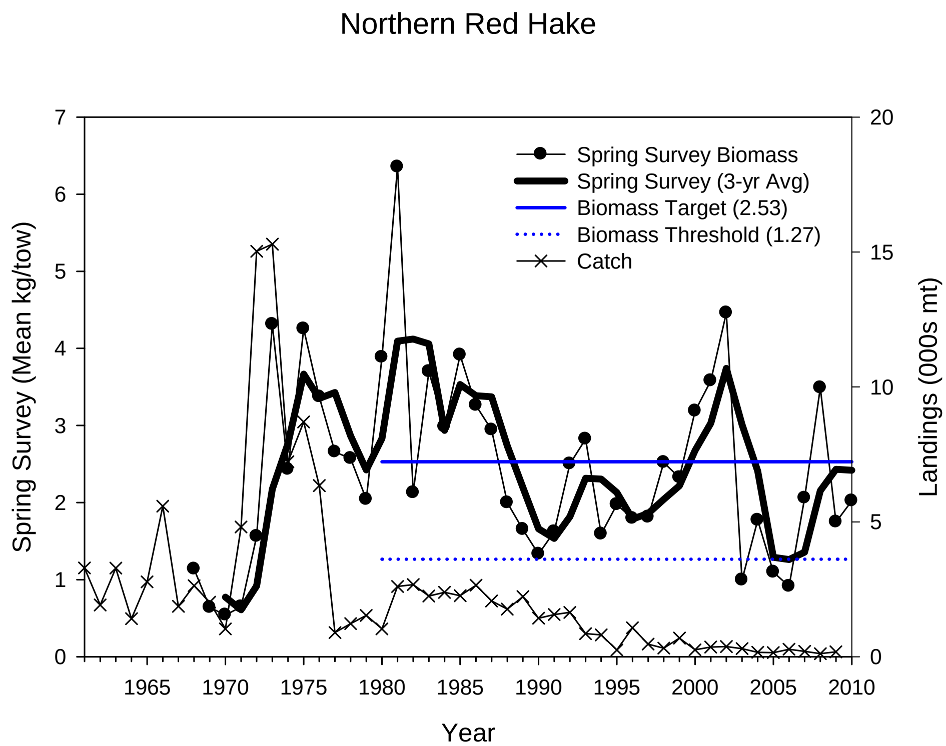
C2. Fall survey biomass (delta transformation) and current BRPs (as opposed to "proposed" BRPs) for the **northern** stock of red hake.



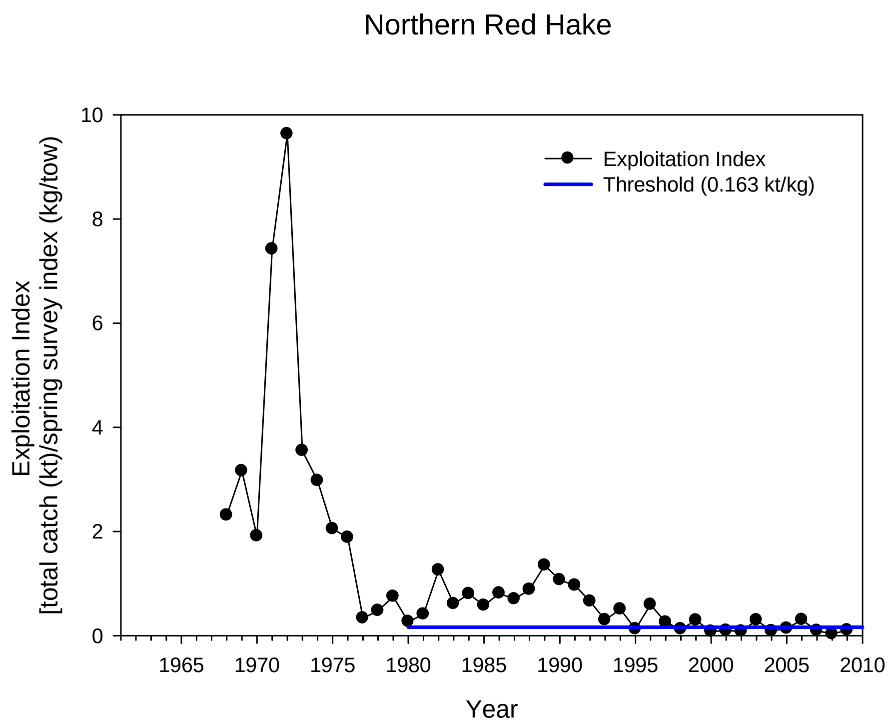
C3. Exploitation Indices (delta transformation of fall survey) and current BRPs (as opposed to "proposed" BRPs) for the **northern** stock of red hake.



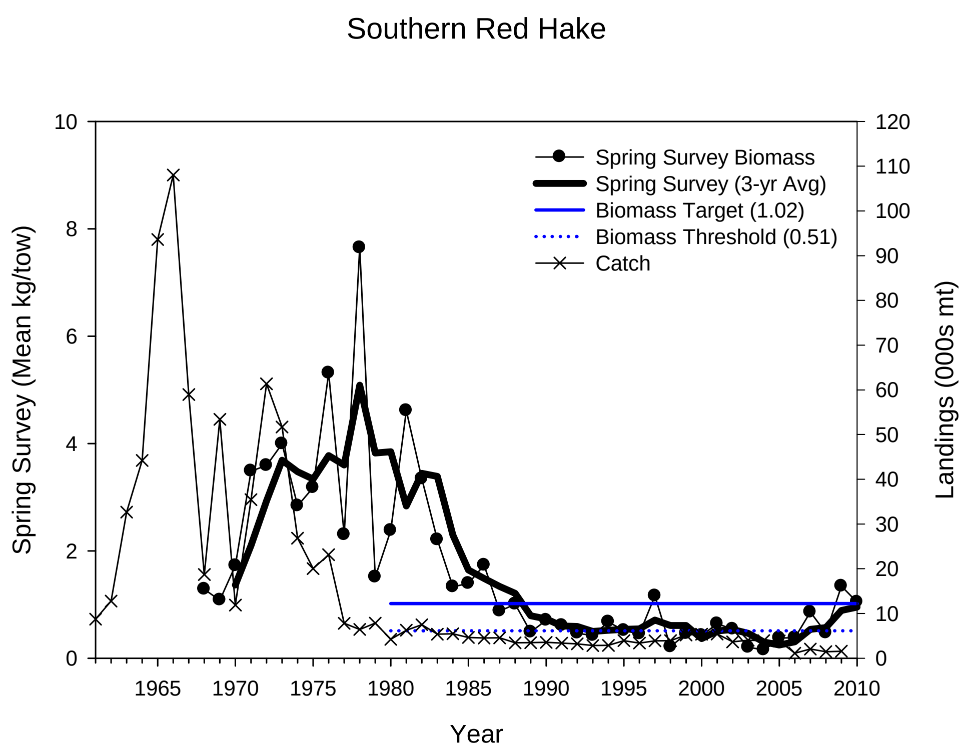
C4. Mean Individual weight (kg)/tow and recruitment index (Number of fish <25cm) from the NEFSC fall survey for the **southern** stock of red hake. Also shown are current BRP (as opposed to "proposed" BRP) thresholds.



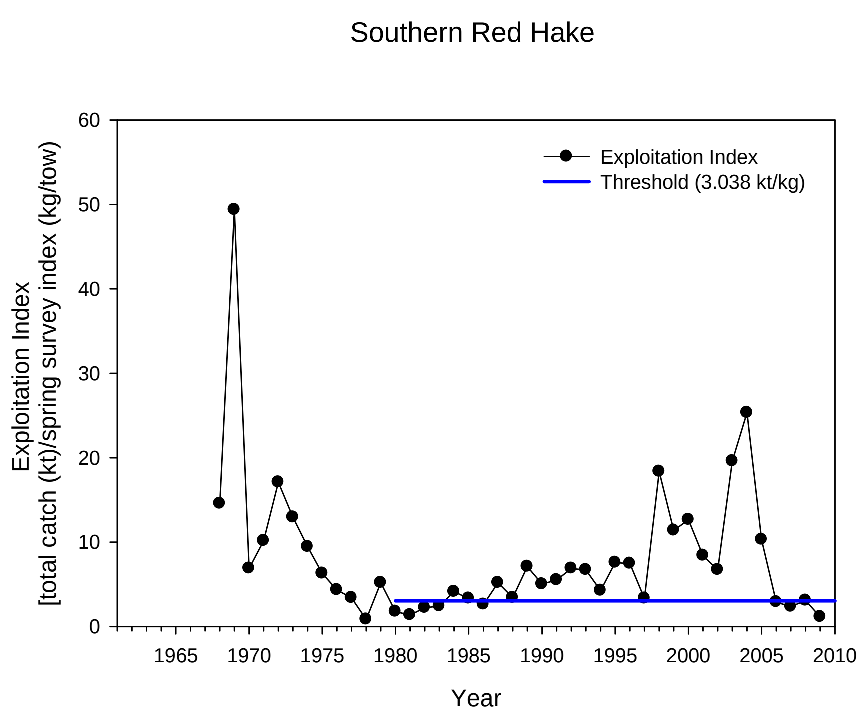
C5. Spring survey biomass and newly proposed BRPs for the **northern** stock of red hake.



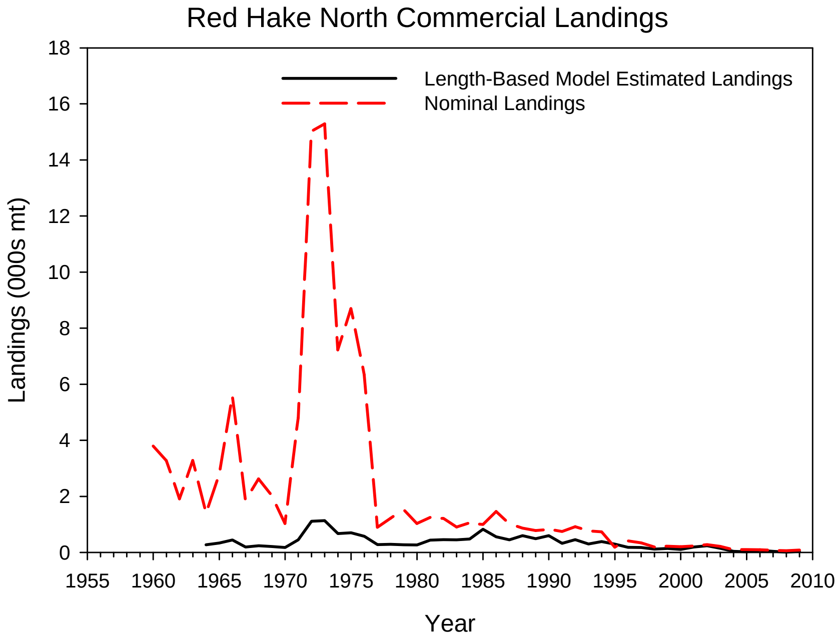
C6. Exploitation indices (spring survey) and newly proposed BRPs for the **northern** stock of red hake.



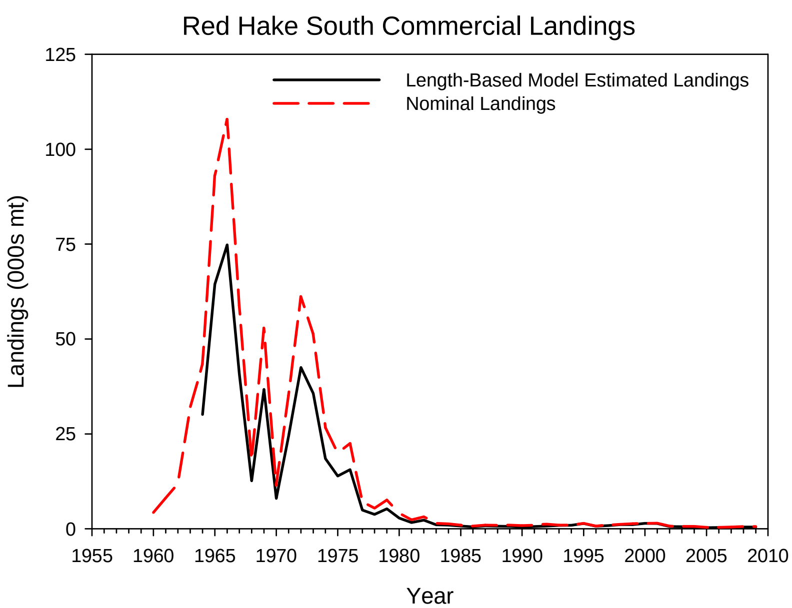
C7. Spring survey biomass and newly proposed BRPs for the **southern** stock of red hake.



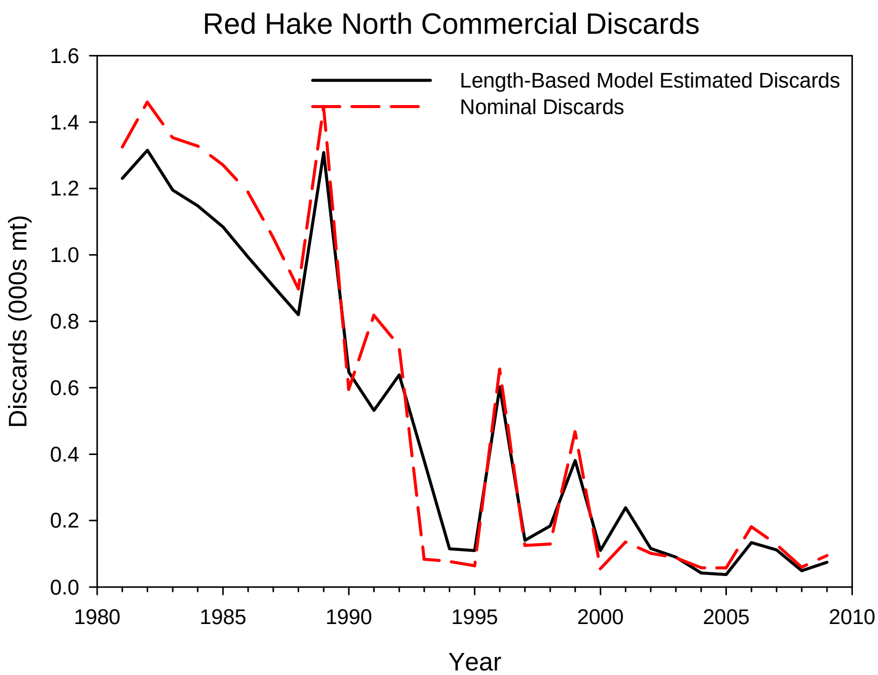
C8. Exploitation indices (spring survey) and newly proposed BRPs for the **southern** stock of red hake.



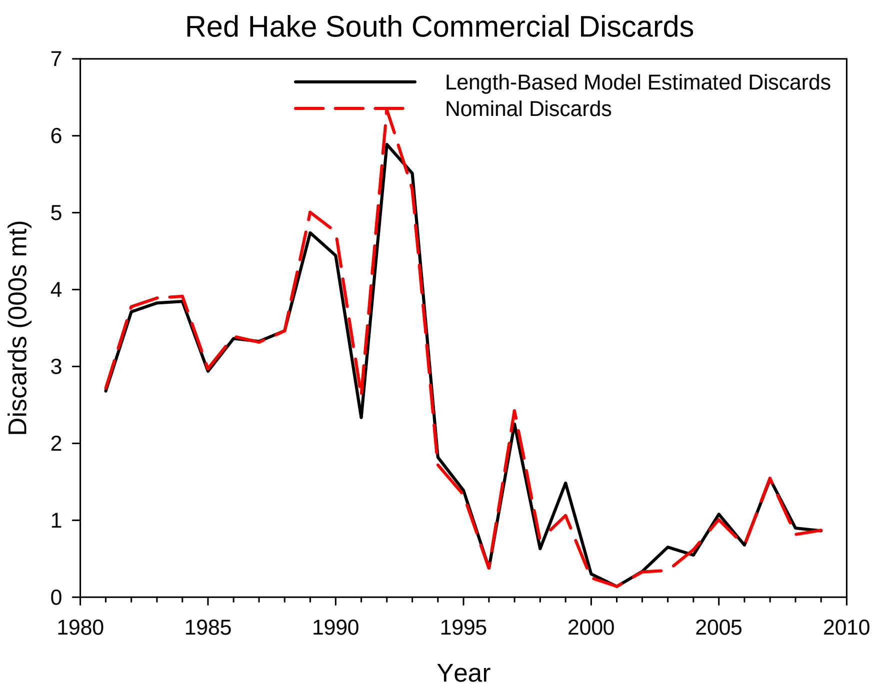
C9. Comparison of nominal landings with length-based model estimated landings of red hake from the **northern** stock. (Length-based estimates were not used in the assessment.)



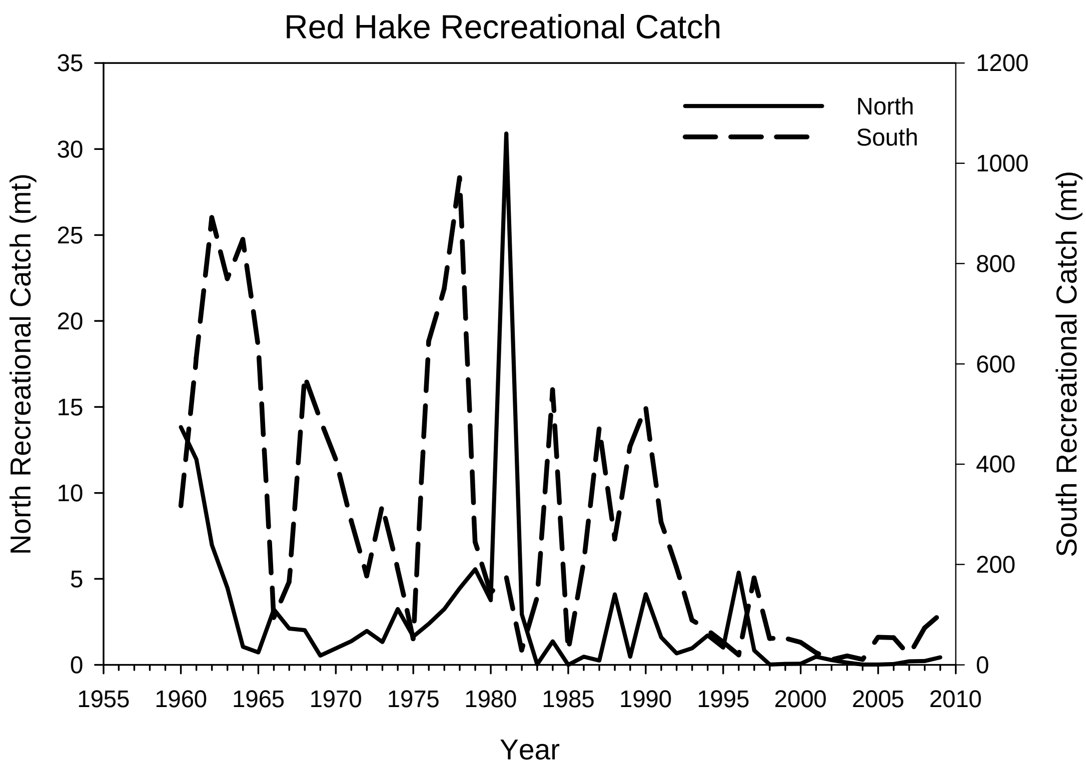
C10. Comparison of nominal landings with length-based model estimated landings of red hake from the **southern** stock. (Length-based estimates were not used in the assessment.)



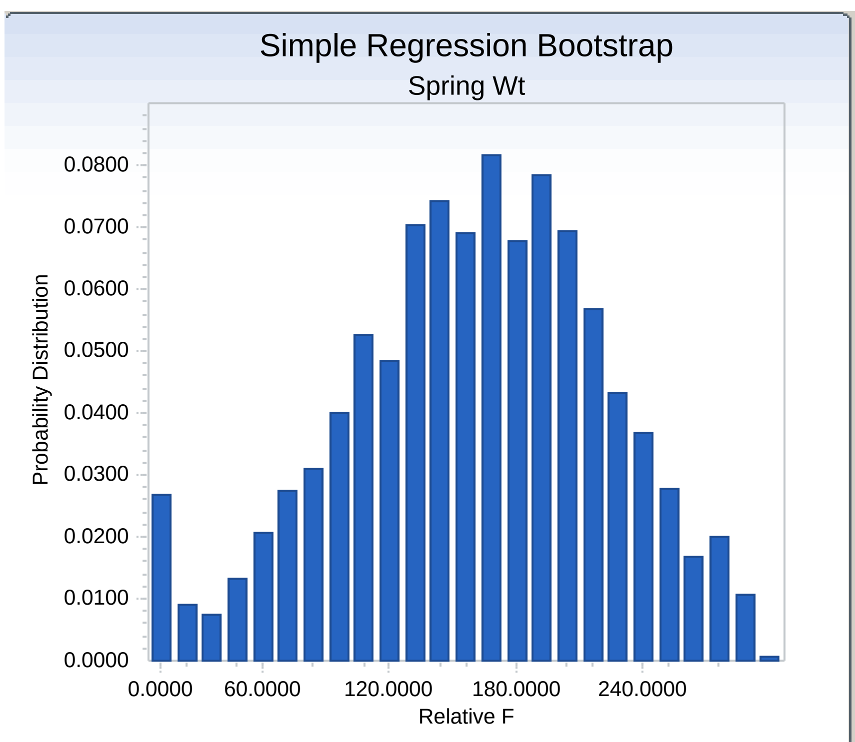
C11. Comparison of nominal discards with length-based model estimated discards of red hake from the **northern** stock. (Length-based estimates were not used in the assessment.)



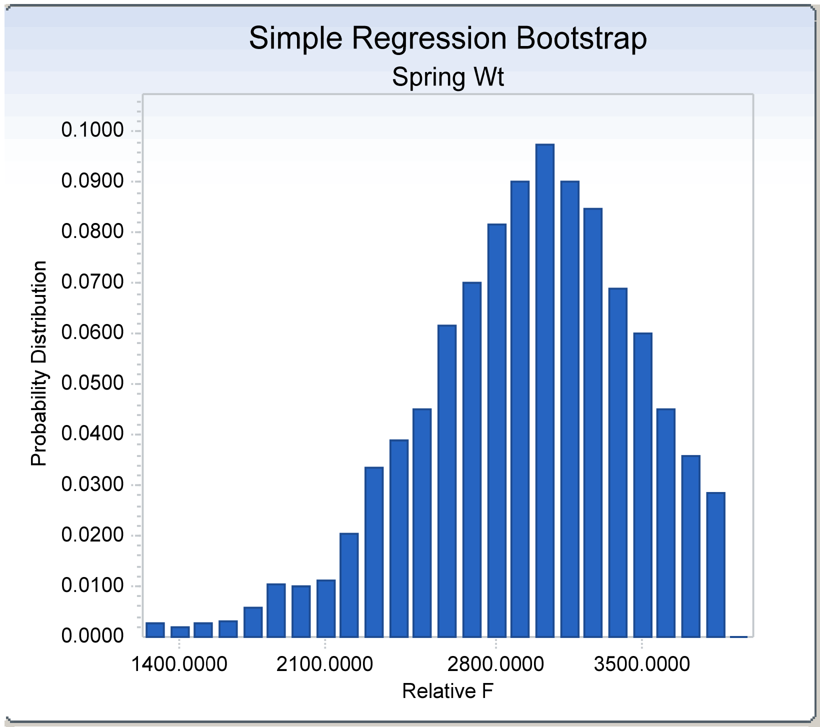
C12. Comparison of nominal discards with length-based model estimated discards of red hake from the **southern** stock. (Length-based estimates were not used in the assessment.)



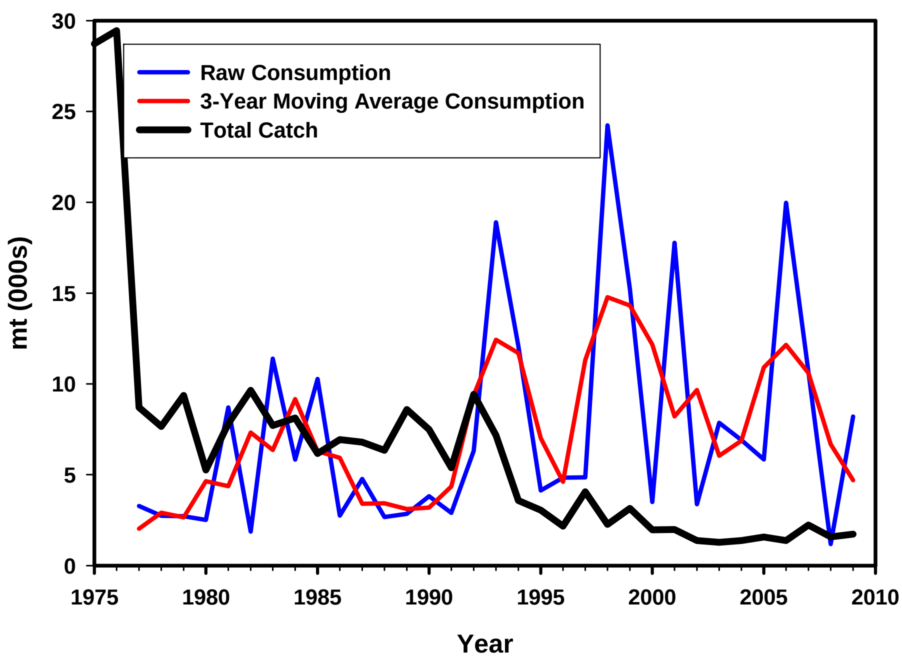
C13. Recreational catch of red hake by area.



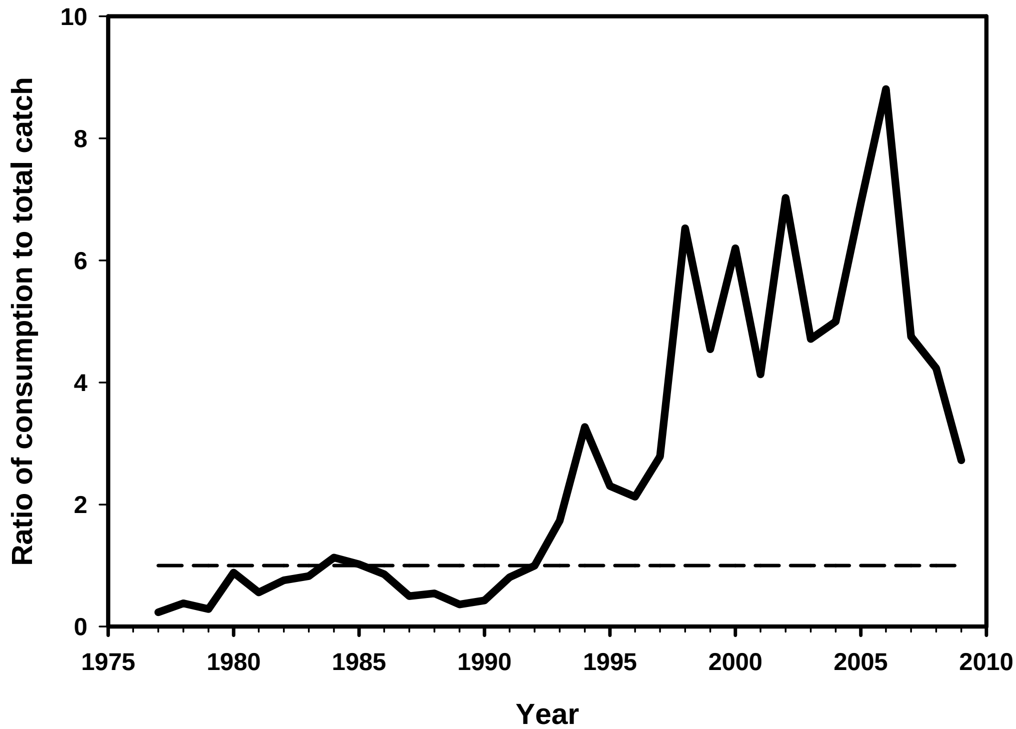
C14. Sampling distribution, from bootstraps, of relative F ([mt catch]/[kg/tow in survey]). Analysis considers replacement ratio and relative F for spring survey indices for **northern** red hake.



C15. Sampling distribution, from bootstraps, of relative F ([mt catch]/[kg/tow in survey]). Analysis considers replacement ratio and relative F for spring survey indices for **southern** red hake.



C16. Minimal estimates of total red hake biomass removed by consumption by major fish predators compared to total catch.



C17. Ratio of consumption to total catch of red hake over the time series. The constant line represents a ratio of unity.

D. OFFSHORE HAKE ASSESSMENT SUMMARY FOR 2010

State of Stock

Based on current biological reference points, offshore hake (*Merluccius albidus*) is not overfished and overfishing is unknown. Based on NEFSC fall bottom trawl survey data for 2007-2009, the three year delta individual mean weight index (0.16 kg/individual) is below the management threshold (0.24 kg/individual) (Figure D1), but the three year average recruitment index (0.89 num/tow) is above its threshold (0.33 num/tow) (Figure D2). (See section: Biological Reference Points).

The new 2010 assessment concluded that information is not available to determine stock status because fishery data are insufficient and survey data are not considered to reflect stock trends. Therefore, the current BRPs should be rejected. It was not possible to recommend alternative reference points. Status is therefore unknown.

Projections

Stock projections were not conducted as no model formulation was accepted.

Catches

Nominal offshore hake commercial landings, which have only been reported since 1991, have varied from 120 mt in the early 1990s to less than 5 mt in 2001-2002, the lowest in the time series (Figure D3). Landings and catches data are uncertain because landings of hakes (silver, offshore and red hake) were not reported by species until 1991. Those that are reported may not be identified correctly (Garcia-Vazquez et al., 2009). Two models (length-based and a depth-based) were developed to estimate the proportion of offshore hake landed from the total mixed hake landings based on species composition in the NEFSC trawl surveys. The two model estimates were similar, both were much higher than the nominal landings (Figure D4), and the higher estimates were used in this assessment. Landings may have been as high as 25,000 mt in the 1960s and have averaged 300-600 mt over the last decade, which is much greater than the 13 mt indicated from nominal landings.

Discards from the longline and sink gill net fishery were minimal for silver and offshore hake. Discards from the otter trawl fisheries have been significant and variable for silver hake. The same problem with species identification that exists with landings also exists with discards. There are discards of offshore hake estimated for the north but because the geographical distribution of offshore hake is limited to the southern stock of silver hake, any discards from the northern stock are assumed to be silver hake. The length-based estimator was used to separate hake discards by species for the southern region.

Catch and Status Table (weights in mt): Offshore Hake

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Max[1]	Min[1]	Mean[1]
Nominal Landings	4	2	1	9	18	10	37	12	20	17	119	1	35
Length-Based Split Landings													
US	302	635	463	565	494	288	82	289	84	142	1629	53	474
DWF											12007	6	2376
Total	302	635	463	565	494	288	82	289	84	142	13014	82	1554
Depth-Based Split Landings													
US	856	934	578	482	894	819	459	350	290	331	1872	110	759
DWF											22318	19	3059
Total	856	934	578	482	894	819	459	350	290	331	24189	251	2205
Nominal Discards	8	10	147	3	7	7	5	21	1	31	174	0	14
Length-Based Split Discards	5	14	16	75	46	5	4	7	13	14	221	2	65
Catch Used in Assessment[3]	308	649	479	639	540	293	85	296	97	156	13014	85	1589
Recruitment index[4]	0.06	1.86	0.36	0.55	0.27	0.01	0.71	1.08	0.22	1.38	1.86	0.01	0.40
Recruitment (3-yr moving average)	0.25	0.68	0.76	0.92	0.39	0.28	0.33	0.60	0.67	0.89	0.92	0.06	0.39
Ind Mean Wt[5]	0.21	0.18	0.22	0.32	0.15	0.27	0.16	0.18	0.19	0.10	0.72	0.10	0.28
Ind Mean Wt (3-yr moving average)	0.16	0.18	0.21	0.24	0.23	0.25	0.19	0.20	0.18	0.16	0.43	0.16	0.28

[1]Nominal Landings data based on 1991-2009 (mt). Length and Depth-based Split and catch used in assessment based on 1955-2009. Commercial fishery discard means from 1981-2009. Recruitment and Individual Mean Weight are from 1967-2009.
[2] Foreign landings are for NAFO Areas 5 and 6.
[3]Catch Used in Assessment is the Length-Based Model Estimated Catch.
[4]Number of fish < 30 cm from the NEFSC fall survey.
[5] Mean weight of an individual fish from the NEFSC fall survey.

Stock Distribution and Identification

Offshore hake are distributed off the continental slope of the northwest Atlantic and southward to the Caribbean and the Gulf of Mexico (Chang et al 1999) (Figure D5). They are found from southern Georges Bank through the Mid-Atlantic Bight at depths ranging from 160-550 meters (Bigelow and Schroeder 1953, Klein-MacPhee 2002). Offshore hake and silver hake (*M. bilinearis*) are sympatric over a considerable range of the continental slope, but are often separated by depth (Helser 1996). Due to their similar morphology and spatial overlap, they have been misidentified for years. The fishing industry did not separate the commercial landings of the two species until 1991, and the extent to which they are still landed as a single species is uncertain (Helser 1996).

Data and Assessment

Data used in the assessment include survey indices from the NEFSC fall survey, landings and discards. Models were utilized to apportion the landings and discards into hake species. A length-based landings model used the catch-at-length for silver hake and the proportion of offshore hake at length from the survey to apportion catch. A depth-based landings model used VMS data and depth-based logistic functions from the survey to apportion landings.

The NEFSC bottom trawl survey switched from the FRV *Albatross IV* to the FSV *Bigelow* in spring 2009. Survey data given here are in "*Albatross IV*" units.

Two assessment models were attempted, An Index Method (AIM) and Survival Estimation in Non-Equilibrium Situations Model (SEINE). Neither model was considered adequate for management.

Biological Reference Points
The current definition for an overfished stock is:

> "Offshore hake is in an overfished condition when the three year moving average weight per individual in the fall survey falls below the 25th percentile of the average weight per individual from the fall survey time series 1963-1997 (0.236) **AND** when the three year moving average of the abundance of immature fish less than 30 cm falls below the median value of the 1963-1997 fall survey abundance of fish less than 30 cm (0.33)".

In previous SAFE Reports, the Whiting Monitoring Committee (WMC) noted problems associated with the overfishing definition for offshore hake. Although the current definition is intended to identify an overfished (i.e. low biomass) stock, it is a better indication of overfishing (high exploitation rate). The WMC recommended that the overfishing definition for offshore hake be revisited.

Survey data may not be a good index of abundance (or of mean weight) and may be driven more by changes in distribution of offshore hake rather than changes in abundance. Therefore, no alternative reference points are recommended and the existing BRPs should also be rejected.

Estimates of catches are highly uncertain and a reliable index of stock size is absent. It is not possible to construct biological reference points with such data. If a reliable index of stock size were available and if the uncertainty in catches could be reduced, the ratio of catch to an index of stock size might be a better overfishing index than using the mean weight.

Fishing Mortality
No estimates of fishing mortality are available.

Recruitment
Estimates of recruitment from the fall NEFSC trawl survey are generally noisy (Figure D2).

Stock Biomass
No estimates of stock biomass are available.

Special Comments
The survey does not cover the entire area of the offshore hake stock. Survey indices could represent changes in fish availability in the survey area rather than changes in abundance (Figure D5).

Developing an ACL for offshore hake will be difficult given that the landings cannot be reliably separated. The mixed reporting of silver and offshore hake landings is a major source of uncertainty. It may be reasonable to develop a combined "whiting" ABC and ACL scheme with suitable protection for offshore hake.

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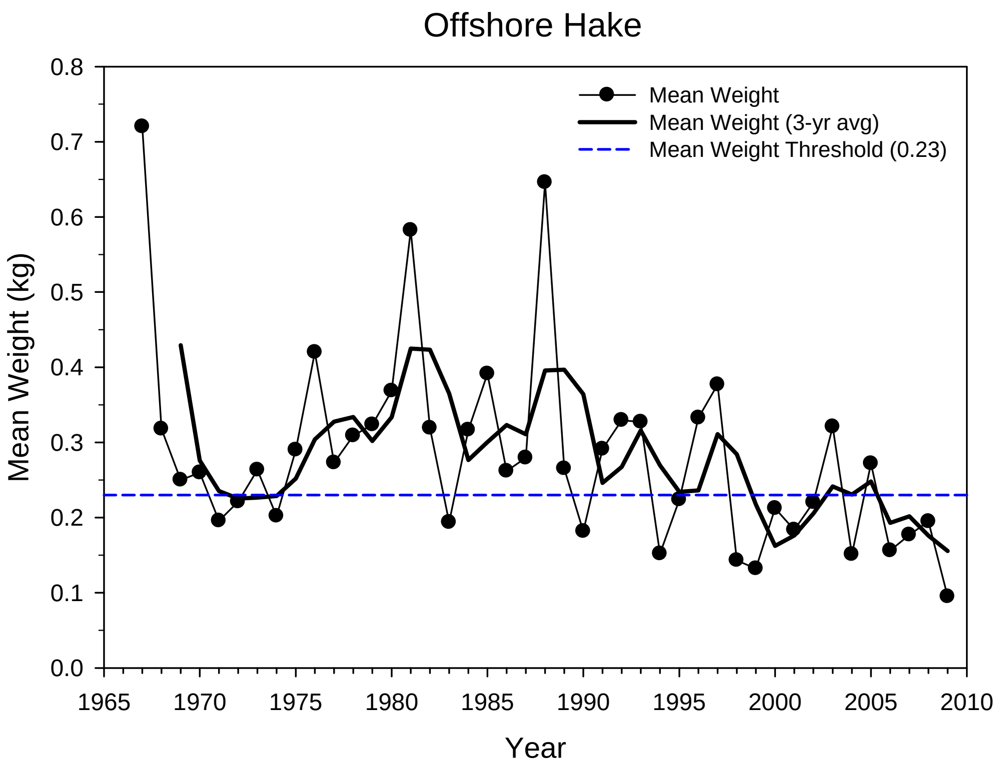
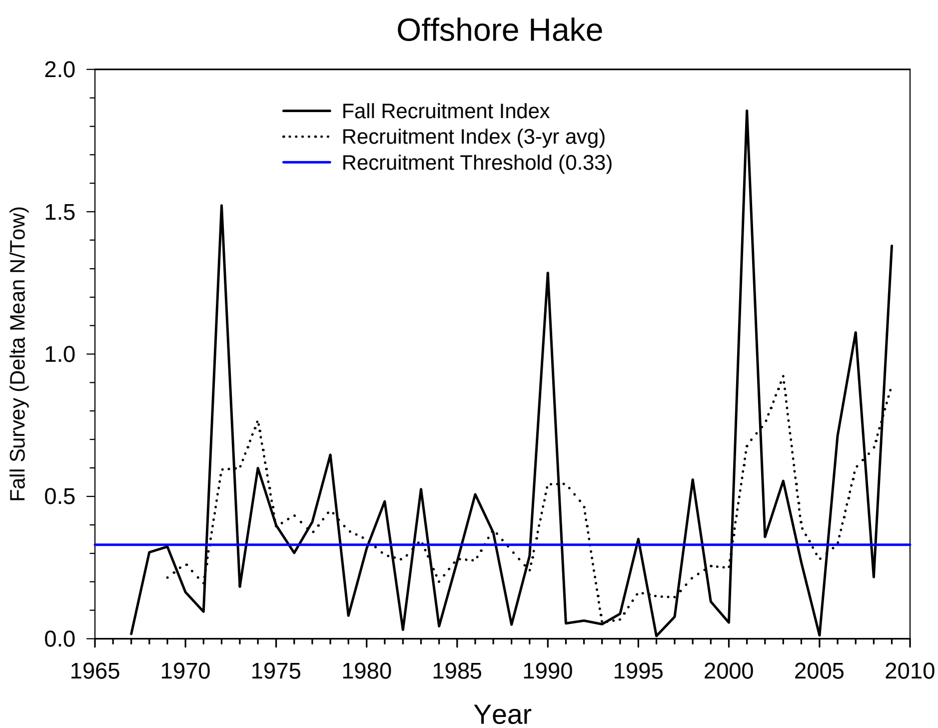
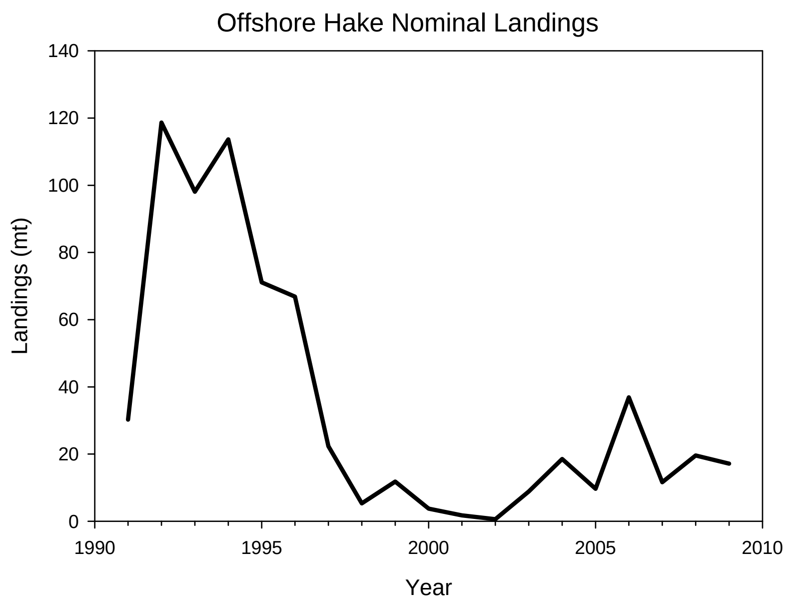


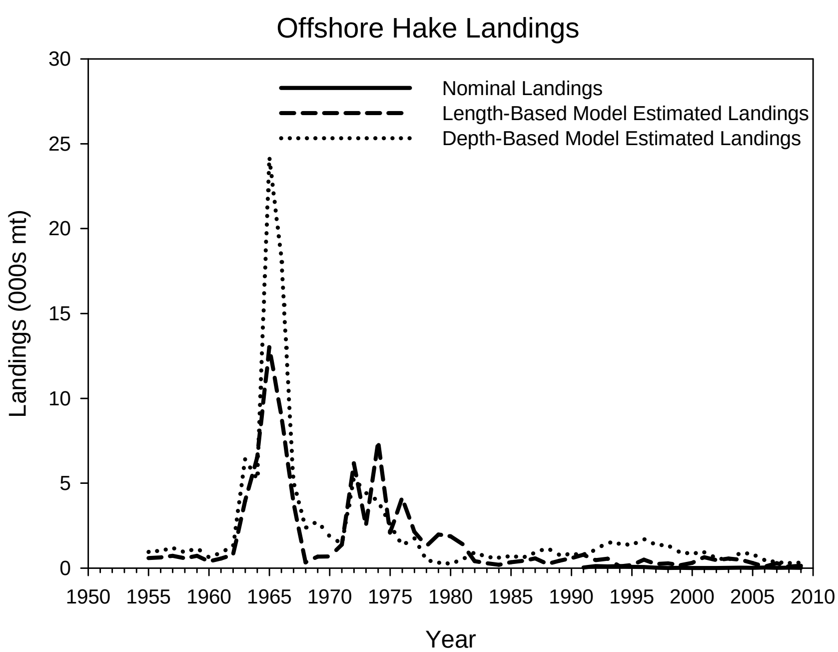
D1. Mean individual weight (kg/tow) of offshore hake from the NEFSC fall survey.



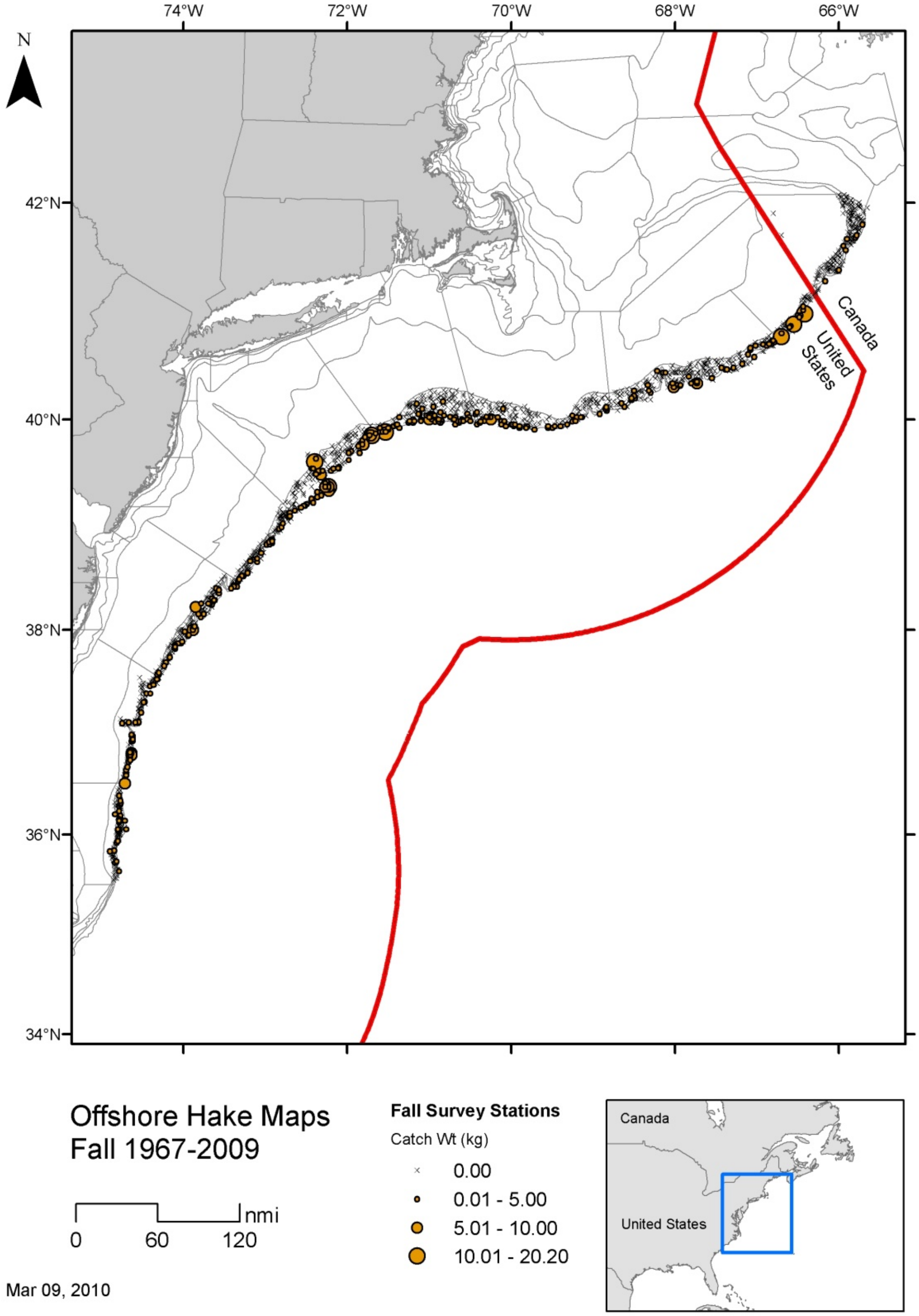
D2. Recruitment index (# of offshore hake <= 30 cm) from the NEFSC fall survey.



D3. Nominal landings of offshore hake (mt).



D4. Landings of offshore hake (000s mt). Comparison of nominal landings to length-based and depth-based estimates.



D5. Distribution of offshore hake in the NEFSC fall bottom trawl survey, 1967-2009.

Appendix: Terms of Reference

Final Assessment Terms of Reference for SAW/SARC51 (11/29 – 12/3, 2010)

(file vers.: 4/23/2010)

A. Silver hake (2 Stocks: Northern and Southern)

For each stock or combined,

1. Estimate catch from all sources including landings, discards, and effort. Characterize the uncertainty in these sources of data, and estimate LPUE. Analyze and correct for any species mis-identification in these data.

2. Present the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, etc.). Characterize the uncertainty and any bias in these sources of data.

3. Evaluate the validity of the current stock definition, and determine whether it should be changed. Take into account what is known about migration among stock areas.

4. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series (integrating results from Silver hake TOR-5), and estimate their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results.

5. Evaluate the amount of silver hake consumed by other species as well as the amount due to cannibalism. Include estimates of uncertainty. Relate findings to the stock assessment model.

6. State the existing stock status definitions for “overfished” and “overfishing”. Then update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the “new” (i.e., updated, redefined, or alternative) BRPs.

7. Evaluate stock status (overfished and overfishing) with respect to the existing BRPs, as well as with respect to the “new” BRPs (from Silver hake TOR 6).

8. Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).
    a. Provide numerical short-term projections (3 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessment (e.g., terminal year abundance, variability in recruitment).
    b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
    c. Describe this stock’s vulnerability to becoming overfished, and how this could affect the choice of ABC.

9. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

B. Longfin squid (*Loligo*)

1. Characterize the commercial catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.

2. Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, age-length data, etc.). Describe the uncertainty in these sources of data.

3. Estimate annual fishing mortality, recruitment and stock biomass for the time series, and characterize the uncertainty of those estimates (consider *Loligo* TOR-4). Include a historical retrospective analysis to allow a comparison with previous assessment results.

4. Summarize what is known about consumptive removals of *Loligo* by predators and explore how this could influence estimates of natural mortality (M).

5. State the existing stock status definitions for the terms "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). Comment on the scientific adequacy of existing BRPs and for the "new" (i.e., updated, redefined, or alternative) BRPs.

6. Evaluate stock status with respect to the existing BRPs, as well as with respect to the "new" BRPs (from *Loligo* TOR 5).

7. Develop approaches for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs), and comment on the ability to perform projections for this stock.
8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

C. Red hake (2 Stocks: Northern and Southern)

For each stock or combined,

1. Estimate catch from all sources including landings, discards, and effort. Characterize the uncertainty in these sources of data, and estimate LPUE. Analyze and correct for any species mis-identification in these data.

2. Present the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, etc.). Characterize the uncertainty in these sources of data.

3. Evaluate the validity of the current stock definition, and determine whether this should be changed. Take into account what is known about migration among stock areas.

4. Estimate measures of annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize their uncertainty. Include a historical retrospective analysis to allow a comparison with previous assessment results.

5. State the existing stock status definitions for the terms "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.

6. Evaluate stock status (overfished and overfishing) with respect to the existing BRPs, as well as with respect to the "new" BRPs (from Red hake TOR 5).

7. Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).
    a. Provide numerical short-term projections (3 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessment (e.g., terminal year abundance, variability in recruitment).
    b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
    c. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.

8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

D. Offshore hake

1. Use models to estimate the commercial catch. Describe the uncertainty in these sources of data.

2. Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, age-length data, etc.). Describe the uncertainty in these sources of data.

3. Estimate measures of annual fishing mortality, recruitment and stock biomass for the time series, and characterize the uncertainty of those estimates.

4. State the existing stock status definitions for the terms “overfished” and “overfishing”. Then update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the “new” (i.e., updated, redefined, or alternative) BRPs.

5. Evaluate stock status (overfishing and overfished) with respect to the existing BRPs, as well as with respect to the “new” BRPs (from Offshore hake TOR 4).

6. If a model can be developed, conduct single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).
    a. Provide numerical short-term projections (3 years). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessment (e.g., terminal year abundance, variability in recruitment).
    b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
    c. Describe this stock’s vulnerability to becoming overfished, and how this could affect the choice of ABC.

7. Propose new research recommendations.

Appendix to the SAW TORs:

Clarification of Terms used in the SAW/SARC Assessment Terms of Reference

(The text below is from DOC National Standard Guidelines, Federal Register, vol. 74, no. 11, January 16, 2009)

On "Acceptable Biological Catch":

Acceptable biological catch (ABC) is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of [overfishing limit] OFL and any other scientific uncertainty…" *(p. 3208) [In other words, OFL ≥ ABC.]*

ABC for overfished stocks. For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan. *(p. 3209)*

NMFS expects that in most cases ABC will be reduced from OFL to reduce the probability that overfishing might occur in a year. (p. 3180)

ABC refers to a level of ''catch'' that is ''acceptable'' given the ''biological'' characteristics of the stock or stock complex. As such, [optimal yield] OY does not equate with ABC. The specification of OY is required to consider a variety of factors, including social and economic factors, and the protection of marine ecosystems, which are not part of the ABC concept. (p. 3189)

On "Vulnerability":

"Vulnerability. A stock's vulnerability is a combination of its productivity, which depends upon its life history characteristics, and its susceptibility to the fishery. Productivity refers to the capacity of the stock to produce MSY and to recover if the population is depleted, and susceptibility is the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery (e.g., loss of habitat quality)." (p. 3205)

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